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Vol. 205 **APRIL, 1928** **No. 4**

CONTENTS

How Can Atoms Radiate?.....H. A. LORENTZ 449
A Few Remarks on the Problem of the Recombination of Positive Ions and Electrons. J. FRANCK 473
New Effects in the Optical Excitation of Vapors.....R. W. WOOD 481
Extreme Ultraviolet Spectra Excited by Controlled Electron Impacts. K. T. COMPTON AND J. C. BOYCE 497
The Green Auroral Line.....G. CARIO 515
Concepts in Quantum Theory.....W. F. G. SWANN 519
Anomalous Kerr Effect in Sodium Vapor.....ARTHUR BRAMLEY 539
Notes from the U. S. Bureau of Standards..... 549
Notes from the Lighting Research Laboratory, National Lamp Works, General Electric Co..... 565
Notes from the Research Laboratory, Eastman Kodak Company..... 569
Notes from the U. S. Bureau of Mines..... 573
The Franklin Institute Notes..... 579
Book Reviews..... 587
Publications Received..... 593
Current Topics.....472, 480, 496, 514, 548, 564, 594

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA
PRINCE AND LEMON STREETS, LANCASTER, PA. 15 SOUTH 7TH STREET, PHILADELPHIA, PA.

SIX DOLLARS PER YEAR (Foreign Postage Additional) **SINGLE NUMBERS, SIXTY CENTS**

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Entered at the Post Office at Lancaster, Pa., March 14, 1928, as second-class matter under act of March 3, 1879.

Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on July 3, 1919.

INDEX TO ADVERTISERS

	PAGE
Ajax Electrothermic Corporation	Second cover page
American Platinum Works	Fourth cover page
Baldwin Locomotive Works	Fourth cover page
Bilgram Machine Works, The	v
Borden, John, & Bro	v
Commercial Photo Engrav. Co.	vi
Drexel Evening Diploma School	Fourth cover page
Electrical Testing Laboratories	v
Fidelity-Philadelphia Trust Co.	iii
Foster, Edgar H., & Son	v
FRANKLIN INSTITUTE, Awards of	viii
FRANKLIN INSTITUTE, "The Electron in Chemistry," by Sir Joseph John Thomson	xi
FRANKLIN INSTITUTE, Award of Elliott Cresson Medal	iv
FRANKLIN INSTITUTE, March Journals Wanted	vi
FRANKLIN INSTITUTE, Membership, Terms and Privileges	ix
FRANKLIN INSTITUTE, Pamphlet Reprints of Lectures and Other Contributions	vi
FRANKLIN INSTITUTE, Award of Howard N. Potts Medal	x
FRANKLIN INSTITUTE, Reprint Henry E. Ehlers, Esq. "Broad St. Subway"	xi
Girard Trust Co.	Second page cover
Glynn Kohler Printing Co.	v
Griffin, John J., & Co.	ii
Groschupf & Fehr	v
Human Research Corporation	Fourth cover page
Journal of Scientific Instruments	Third cover page
Lippincott, J. B., Company Publishers	vii
Lonergan, J. E., Co., Oilers, etc., Philadelphia	v
L'Universo	Third cover page
Oeters Co., Edgar O.	v
Philadelphia Electric Co.	ii
Riehlé Bros. Testing Machine Co.	vi
Sadtler, Samuel P., and Son, Inc.	vi
Smith, Haseltine, Insurance	v
Wetherill, Dr.	vi
White Engineering Corporation, The J. G.	v
Wood, Alan, Iron & Steel Co.	Second cover page

Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 205 APRIL, 1928 No. 4

HOW CAN ATOMS RADIATE?[1]

BY

H. A. LORENTZ, Ph.D., F.R.S.

Director, Teyler Physical Laboratory, Haarlem,
Professor of Physics, University of Leiden, Franklin Medalist, Member of the Institute.

NOTE: Just when the manuscript of this paper was being prepared for the printer, the sad news of the death of Dr. H. A. Lorentz was received. His death takes from us one of the most outstanding figures in the realm of mathematical physics, and an inspiring and sympathetic leader in scientific thought. THE EDITOR

WHEN, some months ago, the secretary had the kindness to ask me to deliver this lecture, I was glad, for various reasons, to accept the invitation. In the first place, and this would have been sufficient, because the great name of Benjamin Franklin, for whom I have always felt a deep veneration, is connected with this place. Secondly, because your Institute once did me the honour to award me the Franklin medal, which, to every man of science, is a very great distinction. I was not, at the time, able to come to Philadelphia to receive the medal but it would have been very unkind on my part, if I had not availed myself of this opportunity for expressing my thankfulness and appreciation.

Now, I suppose that you desire me to lay before you some questions taken from the newer development of physics

[1] Presented at a meeting held Thursday, March 31, 1927.

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and with which I am more or less familiar. So I chose as my subject the way in which the atoms of luminous bodies emit their radiations. Of course, this problem is intimately interwoven with the question, What is the nature of these radiations themselves? So long as, following Newton, physicists supposed light to consist of small particles or corpuscles moving along at high speed, it was natural and necessary to consider the atoms as something like small guns emitting these corpuscles. On the other hand the undulatory theory of light developed by Huygens, Young and Fresnel makes us think of vibrating particles more or less comparable with the vibrating bodies which produce sound.

You know that by a most remarkable change of views modern physics has been led to what one may call a revived corpuscular theory. Numerous phenomena, in the first place those of photo-electricity, can hardly be understood if the energy of light waves is supposed to spread out indefinitely over greater and greater spaces. It seems beyond doubt, that by such a diffusion the energy would soon become too dilute to eject an electron from an atom, for which a definite amount of energy is required. So, one naturally came to the hypothesis of "light quanta," portions of energy concentrated in extremely small spaces and moving onward with the velocity of light.

There can be no doubt as to the amount of energy which must be associated with such a quantum. Phenomena and considerations into which I cannot now enter have shown that this amount must be proportional to the frequency, i.e. to the number of vibrations per second, of the light considered. It can therefore be represented by the product of the frequency n and a certain constant coefficient which we shall denote, as is always done, by h. This is Planck's famous coefficient, which was introduced into science somewhat more than 25 years ago and which has come to play a most important part in many chapters of physics. Planck, indeed, was the first to realize that the continuity which observation first reveals to us in physical phenomena, may be found to be

apparent only when we penetrate farther and farther into minute details. In order to explain the way in which the radiation of heat of different wave-lengths depends on temperature he supposed that in hot bodies there are small vibrating particles endowed with the curious property that they cannot take and lose energy in any arbitrarily small amount, but only in finite portions of definite magnitude, these portions, or elements of energy, as Planck originally called them, being proportional to the frequency. He therefore denoted their magnitude by hn.

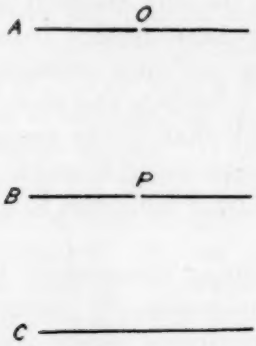
The quantum theory, started in this way, rapidly developed. It may be said to have revolutionized physics; the idea of a definite frequency and a definite amount of energy belonging together in the way assumed by Planck has proved most fruitful. It has been applied to a wide range of phenomena and the value of Planck's constant has been deduced from many of them. To give you at least some idea of this magnitude, I may say that, if the frequency were a billion per second, the quantum would be equal to the work required to raise a weight of 0.0067 milligram to a height of a billionth of a centimetre.

That, notwithstanding the mystery that still hangs over its fundamental assumptions, the quantum theory contains something closely approaching reality, is shown by the striking agreement between the values found for the constant h in different ways. Altogether the theory has been so successful that nowadays we cannot think of a picture of the physical world in which the constant h would not appear, any more easily than we can imagine one in which there would be no question of the elementary electric charge, of Avogadro's constant or of the constant of gravitation.

To return to the light quanta, their energy hn is so small that the number of quanta which our eye receives during a second, for instance, even when feeble light enters it, must be extremely great; they are to be counted by millions. All these quanta have to be emitted by the radiating atoms, and here we may remark that we can more easily conceive a

continuous emission of them than one of corpuscles. These latter have always been regarded as substantial, whereas the light quanta are not material at all, being merely small amounts of energy; they may disappear by the transformation of this energy into some other form, into heat for instance, and similarly they may start into existence provided only that the ejecting atom has a sufficient amount of energy at its disposal. According to an extreme form of the quantum theory not only would there be light quanta but they would be the only constituents of a beam of light, there being nothing like waves or vibrations outside them. If this were so, we should have to seek a new interpretation of the phenomena

FIG. 1.



of interference and diffraction that were so beautifully explained by the old theory of optics. One has indeed tried to do so and with some success. Yet, to my mind, the difficulties which one encounters are so serious that no choice is left us and that *this extreme form* of the theory must be discarded.

A single example will, I think, suffice to justify this conclusion.

Let us observe a diffraction phenomenon produced by means of *very feeble* light. A small opening O (Fig. 1) in an opaque screen A may serve as source of light and a second hole P in a screen B as the diffracting opening. We observe the diffraction image or pattern on a third screen C at some distance behind B.

The image shows a distribution of light and darkness which depends on the shape of the opening in *B* and which can be perfectly calculated by means of the formulae given by Fresnel. These enable us exactly to determine in all its details the delicate structure of the beam of light behind screen *B*, of which we see different sections when we displace screen *C* parallel to itself.

Now, suppose that the effect, the light which we *see*, is due to quanta. Then, either they must move in such a way that they can reach only the bright places on screen *C* or, if they can come to all points, it must be only at the bright places that they are able to illuminate the screen. The first alternative would require that the quanta be properly guided in their course, and if there were nothing else, this ought to be done by some mutual action. The possibility of this, however, must be excluded because one can easily realize circumstances under which the number of quanta to be found at any instant between the planes *B* and *C* is very small so that they are too far apart to act upon each other as would be required.

I had a case, for instance, in which from the intensity of the light and the known magnitude of the quanta I deduced that, per second, about seventy millions of them passed through the opening in the screen *B*. If we take into account that they move with the speed of light and that therefore those that pass in a second are distributed over a length of three hundred millions of metres, one sees that in the case considered the mean distance of successive quanta along the beam was about 400 cm. As the distance from *B* to *C* in the experiment which I have in view was no more than 16 cm., the number of quanta present in the beam between *B* and *C* was on an average 0.04. This means that most times there was in this space no quantum at all; at some instants there will have been one quantum between the two planes and sometimes there may have been two or more of them, but this must have been a very rare occurrence.

We may conclude from this that there can be no question

of the motion of the quanta being controlled by some mutual action. There must be something of another kind which determines their course. Similarly, if we choose the other alternative just mentioned, there must be something else besides the quanta, on which it depends whether or not they shall be able to illuminate the screen.

Now this "something" must account for all the details of the diffraction phenomena which we can calculate with our old wave-theory and so it seems to me very natural to assume that, if there are quanta, which I shall not deny, there must be besides them something like the ordinary radiation field with which we have long been familiar. For this reason and for the sake of briefness, I shall now dismiss the light quanta altogether and shall simply speak in what follows of the emission of vibrations.

I shall put before you four different theories of this emission, the one that was universally accepted until thirteen years ago, the most remarkable theory developed by Bohr in 1913, the "dynamics of matrices," as it is called, which we owe to Heisenberg, Born, Jordan and Dirac, and, finally, a theory that was put forward by Louis de Broglie and in the evolution of which Schrödinger had a great part.

In the oldest of these theories, the "classical" one as it is often named now, the atoms were supposed to contain small particles which have definite positions of equilibrium and can vibrate about them. Suitable assumptions were made concerning their masses and the forces acting on them, but as to their nature little progress was made, until one came to realize, and this was an important step, that they must be electrically charged. I may, perhaps, briefly review the grounds on which this latter assumption is based.

In the first place one learned to know by Maxwell's theory, that the waves of light are of the same nature as the waves observed by Hertz or as those that are used in wireless telegraphy. The wave-length of light is much smaller, but the general laws for its propagation are identical with those of the electromagnetic waves. One might suppose therefore

that the light waves have their origin in something comparable with the alternating electric currents in a Hertz vibrator, or in the aerial of a wireless installation.

In the second place, a celebrated experiment made by Rowland has shown that the same effects that are produced by conduction currents in a metal can be brought about by what is called a convection current, namely by the motion of a charged body. A charged hard rubber disc, rapidly rotating in its plane, deflected a magnetic needle suspended at some distance in exactly the same way as could be done by a current flowing in a circular coil. The experiment has been repeated in many different forms and there can be no doubt that, when a charged sphere, for instance, is moved to and fro along a straight line it will produce waves of the same kind as can be obtained by an alternating current along that line. Something like this sphere, on a much smaller scale, a minute particle carrying an electric charge and vibrating in the interior of an atom, might well be the origin of the light which the atom radiates.

There are many other grounds for the assumption of small charged particles, ions or electrons as they have been called. The hypothesis makes it possible also to understand the phenomenon of the absorption of light, which is the inverse of the radiation and which we shall also have to consider. It is immediately clear that now part of the motion existing in the incident waves is communicated to the body. Thus, in this case, particles must be set vibrating *by the light* and this is what can be expected when they carry electric charges. According to Maxwell's theory the beam of light is the seat of rapidly alternating electric forces and by definition such a force is one by which a charged body can be set into motion.

I think you now see the main features of the picture which the old theory gave us of optical phenomena. The charged particles in a luminous body are drawn towards their positions of equilibrium by forces, proportional to the distances over which they have been displaced from these positions. So each of them can vibrate with a definite frequency, just as an

ordinary pendulum or a tuning fork, and by this the frequency of the emitted radiation is likewise determined. If now, this radiation falls on the matter of a ponderable body, different things may happen, but at all events the beginning will be that the electrons or ions in the body are set vibrating. If the body is found to be not wholly transparent, we may conclude that there is some kind of resistance opposing the regular motion and converting it more or less into the irregular agitation which manifests itself as heat. In a transparent body like air or glass there is no such resistance and then it is found theoretically that the optical properties, namely the velocity of propagation *in* the body and the index of refraction

FIG. 2.

are determined by the amount to which the electricity in the body is displaced by the periodically changing electric force in the beam to which it is exposed. If, under the action of a given alternating electric force, there is a considerable displacement of electricity in the direction corresponding to that of the force, we shall have a small velocity of propagation, showing itself in a high index of refraction.

This old theory certainly had a great beauty though it must be owned that its success was largely due to the fact that, not knowing very much about the structure of atoms, physicists felt free to make, concerning the particles and the forces that act upon them, just the hypotheses that best suited their purpose. Let me give you one or two examples

of what could be done with the theory and then point out to you its great failures.

I may mention as a success the explanation of different phenomena by means of the principle of resonance. What I want to say is best illustrated by a simple experiment. Let *ns* (Fig. 2) be a small compass needle and let the south pole of a bar magnet be moved to and fro along the line *AB* situated in the horizontal plane in which the needle can move and at right angles to its direction of equilibrium *ns*. The motion imparted to the needle will then depend on the relation between the frequency of its free or natural vibrations, i.e. those which it can perform under the sole action of terrestrial magnetism, and that of the oscillations of the pole *P*. If, first, *P* is kept fixed in any position on *AB*, the needle will take a new position of equilibrium the end *n* being deflected towards the right when *P* is on the side *B*, and towards the left when *P* is on the side *A* of the middle point *O*. When, next, the pole *P* is slowly moved to and fro, the needle obediently follows it, being at any moment nearly in the position of equilibrium corresponding to the place of *P* at that moment. The amplitude of these "forced" vibrations is found to increase when, by raising the frequency of *P*, we make it approach that of the free vibrations of the needle. This goes so far that, when the two frequencies have become equal, the amplitude would become infinitely great in the ideal case of no resistance. But most curious and at first sight somewhat strange is what happens when we make the pole *P* oscillate more rapidly than corresponds to the natural frequency of *ns*. The forced vibrations then take a phase opposite to what we had first, so that at a definite moment the needle is deflected in a direction opposite to that in which it is drawn by the pole *P*. The end *n* will be on the right-hand side when *P* is near *A*, and on the left-hand side when *P* is near *B*. Again the amplitude of the forced vibrations will be greatest when the difference between the two frequencies is small. Let us now apply this to the propagation of light in a body, replacing the force due to the magnetic

pole P by the alternating electric force existing in a beam of light and the magnetic needle by the movable particles in the body. We shall suppose that there are various kinds of such particles, with different natural frequencies and that the displacement of electricity by the motion of all these kinds together is in the direction corresponding to that of the electric force. Let us now, however, see what contribution to this general displacement is due to the particles of one particular kind. These will have, just like our magnetic needle, a definite frequency of their own, say n_0, and if the frequency of the incident light had exactly this value, we should have the maximum of resonance. The resistance to the vibrations, some kind of which we can imagine always to exist, will give rise to an absorption which now will be greater than for any other frequency of the incident light. Thus, if while light falls on the substance, we shall have in the spectrum of the transmitted rays an absorption band, the middle of which has a position corresponding to the natural frequency of the group of particles considered.

Suppose, now, that the frequency of the incident light is somewhat smaller than n_0. Remembering what we saw in the case of the magnetic needle we can easily foresee that the particles in question will be displaced in the direction in which they are driven by the electric force. Hence, owing to this group of particles, the displacement of electricity in the direction of the electric force will be greater than it would be without them. The reverse will occur when the frequency of the incident light is greater than n_0. Then, at any moment, the particles now considered will be displaced in a direction opposite to that in which they are driven by the electric force and this will tend to diminish the total displacement which we have supposed to be in the direction corresponding to the electric force. Finally, if we take into account the relation between the displacement of electricity and the index of refraction, we see that the presence of particles with the natural frequency n_0 will increase the index of refraction for light whose frequency is below n_0 and diminish it for rays

whose frequency is above that value, both effects diminishing when n recedes from n_0 because by this the amplitude of the vibrations set up by the electric force becomes smaller.

These conclusions have been amply confirmed by experiment and all the phenomena of dispersion, i.e. those in which we are concerned with the way in which the velocity of propagation depends on the frequency, can be very satisfactorily explained on this basis.

The second problem in which the old theory has had, one may say, a brilliant success, is that of the scattering of light by the molecules of a body, if they are irregularly distributed over space, as is the case in liquids and gases. The movable charged particles contained in the molecules are set in motion by the incident light and thereby become themselves centers of emission. Consequently, the light does not remain confined to the direction of the incident beam; part of it is thrown sideways in different directions, and this of course implies a diminution of the intensity of the light that continues its course in the original path. The two phenomena, the "extinction" as the beam proceeds, and the scattering, are so closely connected that the degree to which one of them takes place follows directly from the numerical value that measures the other. Both are determined by what is known as the "extinction coefficient," the definition of which is as follows.

Let the intensity of a beam be measured by the amount of energy that is carried across a section per unit of time, and consider its diminution when the beam goes forward over a small distance l. Dividing this diminution by the length of l one finds the extinction per unit of length, and division of this by the intensity such as it is at the beginning of the distance l will give one the extinction coefficient k. If, for instance, $k = 0.001$, the intensity will decrease by one-thousandth part of its amount, when the rays go forward over a distance of a centimeter.

The coefficient of extinction is given by a celebrated theoretical formula which we owe to the late Lord Rayleigh, namely

$$k = \frac{32\pi^3(\mu - 1)^2}{3N\lambda^4},$$

where $\pi = 3.1416$; N is the number of molecules per unit of volume, λ the wave-length of the light and μ the index of refraction.

The equation has been verified by accurate measurement of the extinction in gaseous media and the values of N to which it leads are in good agreement with the results obtained in other ways. But I must now call your attention to the deficiencies of the old theory. One of its worst failures was that it could not account for the structure of spectra, I mean to say, for the regularity in the spectra which shows itself in the numerical relations between the frequencies of the lines. The analogy with the phenomena of sound, on which much stress was laid in the old theory, was rather misleading than helpful when one tried to understand these relations.

Every one knows that a stretched string can give a series of tones, the fundamental tone and the upper harmonics, each of which is produced by a particular mode of vibration. The frequencies of these tones are proportional to the natural numbers 1, 2, 3, $\cdots$, a law which was deduced long ago from a mathematical theory which also made it possible to calculate the pitch of each tone when one knew the tension of the string and its mass per unit of length. By means of a similar theory, only of somewhat greater mathematical complexity, we can determine the modes of vibrations of other systems, of stretched membranes, for instance, and of rods or spheres of elastic substances; in these cases also the ratios between the frequencies of the different tones, though in general less simple than in the case of the string, can be completely accounted for. Now, the existence, in the spectrum of a gaseous body which is a chemical element, of a certain number of lines, clearly shows that, just as vibrating bodies of the kind I have mentioned, atoms of a definite constitution can send forth waves of different frequencies. It was natural to expect, here also, some numerical relation between the frequencies; and such a relation has really been brought to light;

its form, however, is such that it has baffled all attempts to deduce it by considerations like those used in the theory of elasticity.

It will suffice for our purpose to discuss the simplest case, the ordinary spectrum of hydrogen glowing in a Geissler tube. It consists of a series of lines, which are ordinarily distinguished by the letters α, β, γ, $\cdots$. The line α is seen in the red; β and γ are likewise in the visible spectrum and the remaining ones have their places in the ultraviolet. The law which governs their positions, was discovered, half a century ago, by the Swiss physicist, Balmer. It has been found to be in perfect agreement with the observations; in fact, it is equalled in this respect by few other physical laws.

We can express Balmer's law by saying that the frequencies of the lines α, β, γ, $\cdots$ are proportional to the quantities

$$\frac{1}{4}-\frac{1}{9}, \qquad \frac{1}{4}-\frac{1}{16}, \qquad \frac{1}{4}-\frac{1}{25}, \qquad \cdots,$$

the series of which you can easily continue, the formation of the successive terms being at once apparent

It is seen immediately that, as we proceed in the series, the terms, though continually increasing can never go beyond the lines $\frac{1}{4}$, which, of course, implies that the differences between successive frequencies become continually smaller and tend towards zero. These differences are proportional to the quantities

$$\frac{1}{9}-\frac{1}{16}, \qquad \frac{1}{16}-\frac{1}{25}, \qquad \frac{1}{25}-\frac{1}{36}, \qquad \cdots.$$

This means that as we pass through the spectrum from the side of the red to that of the violet the lines are more and more crowded together (Fig. 3) and that there is a limiting position p to which they come very closely but which they cannot wholly reach. Series of lines presenting these same features are found in the spectra of other elements and we are undoubtedly concerned here with something quite essential and fundamental. Now, this remarkable structure is wholly

beyond the powers of the classical theory; it is impossible to explain it by any assumption about particles vibrating about positions of equilibrium.

FIG. 3.

I should now like to say some words of the wonderful theory by which Bohr has explained the hydrogen spectrum. He did so without having to imagine a structure of the atom specially invented for the purpose. The starting point was the idea, already put forward by Rutherford, that the hydrogen atom consists of a positively charged nucleus and a negatively charged electron circulating around it. The mass of the nucleus is about 1850 times that of the electron and therefore, in a first approximation the nucleus may be supposed to remain at rest. The electron is attracted by it with the ordinary electrostatic force, the law of which is the same in form as that of gravitation, the intensity of the force being inversely proportional to the square of the distance. Thus, the case is much like that of a planet moving around the sun; the electron will in general move in an elliptical orbit. Eventually the orbit may be a circle, and, again for the sake of brevity, we shall confine ourselves to orbtis of this kind. The consideration of elliptical orbits would give us the same result.

Now, how can we, with this simple model of the atom, explain a law so complicated as Balmer's? Bohr has performed this by making two bold assumptions, the one referring to the state of motion of the electron and the other to the emission of radiation.

In Planck's theory of the radiation of heat it had been assumed that each of the vibrators which give rise to this phenomenon can only have one of certain definite amounts of energy, namely, one of the amounts hn, $2hn$, $3hn$, etc., where h is the constant which we know already and n the frequency of the vibrator. Similarly, among all the circular motions of his electron of which one can think, Bohr singles out certain specified ones, assuming that these are the only ones that really occur; he calls them the "stationary motions." The selection is made by the introduction of a condition very similar to the one to which we just now subjected the motion of the vibrator; in a sense, it is the same condition adapted to the circumstances of the new case.

Both the vibrator and the atom of hydrogen have, in each of their states of motion, a definite amount of energy and for both we can distinguish between the kinetic energy and the potential energy. Let us compare these parts of the energy in the two cases, not forgetting that in the expression for the potential energy there is always an arbitrary constant; this is unavoidable because we are free to choose the position in which the potential energy is said to be zero and with which all other positions are compared. The indefiniteness will not affect our results, because these will depend on the differences only between the values of the energy in different states.

The kinetic energy of a moving mass is always given by the product of its magnitude and half the square of the velocity. It is constant for the electron moving in the circle, whereas for the vibrator it oscillates between zero and a certain maximum value; we may in this case speak of its mean value during a full period.

The potential energy of the vibrator—we may think here of an ordinary pendulum because the same is true for all kinds of vibrators—has its smallest value in the position of equilibrium. If this value is taken to be zero, the potential energy will be positive in all other positions and it may be shown that its mean value will be equal to that of the kinetic

energy. Hence, if we take half the total energy we shall have the mean value of each of the two parts.

In the hydrogen atom the potential energy increases when the electron gets farther away from the nucleus. It has its greatest value at infinite distance and if we denote this by C we have, for any finite distance, to diminish C by a certain amount, which we may call the wanting potential energy and which turns out to be inversely proportional to the distance. According to a theorem well known in dynamics the kinetic energy is now equal to half this wanting potential energy, so that the total energy is obtained when we diminish C by half the wanting potential energy. Thus, the total energy increases with the radius of the orbit. If the atom is given in one of its modes of motion, it will require some work to remove the electron to a great distance, even if we are satisfied with having it there without any kinetic energy.

Now, Bohr's assumption may be expressed in the same form as Planck's if we fix our attention upon the kinetic energy. Instead of saying that the total energy of the vibrator must be a multiple of hn, we may just as well require that the mean kinetic energy be a multiple of $\frac{1}{2}hn$. In the case of the hydrogen atom, we can understand by frequency the number of revolutions per unit of time and now, if n is given this meaning, Bohr's hypothesis amounts to this, that the circular motion must be such that the kinetic energy is just a multiple of $\frac{1}{2}hn$. We shall write for it $k \cdot \frac{1}{2}hn$, k being an integral number.

By this, the stationary states are completely defined, and the total energy will be known for each of them because the kinetic energy has been determined. If, after all, the formulae become somewhat less simple than they are for the vibrator, it is only because now the frequency, n, is not a constant, but depends, according to Kepler's third law, on the radius of the orbit.

Working out the necessary calculations one finds for the energy of a stationary state

$$C - \frac{A}{k^2},$$

where the constant A has the value

$$A = \frac{2\pi^2 me^4}{h^2}.$$

In this equation m is the mass of the electron and e its charge, whose magnitude is equal to that of the charge of the nucleus.[2] The different stationary modes of motion are characterized by the values 1, 2, 3, $\cdots$ of the quantum number "k." I may add that the radii of the orbits are in the ratios of 1, 4, 9, $\cdots$.

I now come to Bohr's second assumption. The atom is supposed not to radiate so long as it is in one of its stationary states. An emission of light takes place only when there is a transition from one of these states to another in which the energy has a smaller value. In such a transition or jump the atom loses a certain amount of energy and *this* energy is radiated. As to the frequency of the radiation, it is supposed to be the one that is associated with the amount of energy just mentioned. Thus, if E is the energy of the atom before the transition, in the first stationary state, and E' the energy

[2] Let r be the radius of the orbit and v the velocity of the electron. The force with which the electron is attracted by the nucleus is

$$\frac{e^2}{r^2},$$

so that by the law of circular motion, one has

$$\frac{mv^2}{r} = \frac{e^2}{r^2}.$$

The frequency is

$$n = \frac{v}{2\pi r}$$

and the quantum condition requires that

$$\tfrac{1}{2}mv^2 = \tfrac{1}{2}khn.$$

From these equations one finds

$$r = \frac{k^2h^2}{4\pi^2me^2}$$

and

$$\tfrac{1}{2}mv^2 = \frac{2\pi^2me^4}{k^2h^2}.$$

This is also the value of $\frac{A}{k^2}$.

after the transition, in the final state, so that $E - E'$ is the radiated energy, the frequency is

$$\frac{E - E'}{h}.$$

Following this assumption, we obtain the lines α, β, γ, $\cdots$ of the Balmer series, when we consider a transition from the third, or the fourth, or the fifth stationary state, and so on, always to the second state. Indeed, the energy in the third state is $C - \frac{A}{9}$ and that in the second $C - \frac{A}{4}$, by which the frequency in the case of the first jump becomes

$$\frac{A}{h}\left(\frac{1}{4} - \frac{1}{9}\right).$$

Similarly, we find for the transition from the fourth state to the second

$$\frac{A}{h}\left(\frac{1}{4} - \frac{1}{16}\right),$$

etc. So we really find the ratios between the frequencies of the lines, exactly as they are according to Balmer's law.

But, in addition to this, the absolute values of the frequencies, and not only their ratios, can be calculated. If, as is usually done in spectroscopy, we use instead of the frequency n, the number of wave-lengths in a centimeter, which is $\frac{n}{c}$, when c is the velocity of light, we must replace in our formulae $\frac{A}{h}$ by

$$\frac{A'}{h} = \frac{2\pi^2 me^4}{ch^3}.$$

When, in this expression, we substitute for c, m, e and h their numerical [3] values, we find 109,000, whereas the value deduced from the measured wave-lengths of the lines is 109,700.

[3] $c = 3, 10^{10}$; $m = 8.98, 10^{-26}$; $e = 4.77, 10^{-10}$; $h = 6.55, 10^{-27}$, all in C.G.S. units.

Thus, Bohr has really calculated from known quantities the frequencies of the light emitted by a hydrogen atom, just as we deduce the frequency of a string from its tension, and its mass per unit of length. The agreement is so close that we can scarcely doubt that his formula is the right one.

This theory of the hydrogen spectrum is certainly one of the greatest achievements in modern physics. It is also one of the most fruitful for it has enabled Bohr and those who worked along the same lines to give us an insight into the nature of spectra much more intricate than that of hydrogen. All over the world, spectroscopists are now using Bohr's ideas for disentangling the multiplicity of spectral lines which otherwise would be most bewildering.

Yet, there are many points which we do not understand so well as we might wish. According to the old theory the electron ought already to radiate while it performs its stationary motion in a circle or an ellipse; in Bohr's theory, however, it is not allowed to do so, just because one wants the motion to be stationary. Then we should like to see how it is that only the selected stationary states, and no others, can exist in reality. And, finally, the frequency is simply deduced from the amount of energy that is available for radiation. We should certainly be more satisfied if in the picture there were something like a vibrator, as we formerly imagined it. In connection with this I must remark that the orbital motions themselves are periodic but their frequencies are wholly different from those of the emitted radiations. The red hydrogen line, for instance, is due to a jump from the third stationary state to the second. In these two states the frequency is $\frac{2}{27}\frac{A}{h}$ and $\frac{2}{8}\frac{A}{h}$ respectively, whereas the frequency of the emitted light is

$$\frac{5}{36}\frac{A}{h}$$

The three numbers are proportional to 8, 27 and 15.

The difficulties which I pointed out to you now are so

serious that many physicists have been led to the idea that some radical change in our fundamental dynamical conceptions will have to be made. I shall conclude with some remarks about two new and remarkable theories which have this tendency.

The first of these theories has been developed by Heisenberg, Born, Jordan and Dirac; it is usually called the dynamics of matrices. To my regret I can scarcely give you an adequate outline of it; I cannot even explain to you in a short time what mathematicians understand by a "matrix." I must confine myself to the general idea underlying the theory.

When, following Bohr, we want to calculate the frequency of the radiation emitted by hydrogen, we proceed in three steps. First, we determine the motions, in elliptical or circular orbits, that are possible according to ordinary mechanics. Then, we select among all these motions those which satisfy certain quantum conditions; these are the stationary states. Finally, we fix our attention on one of the transitions of which I have spoken. The difference between the values of the energy, before and after the transition, gives us the frequency of one of the spectral lines. The formula which we find for it, contains the charge e of the electron, its mass m and Planck's constant h.

Now, the fundamental idea of the physicists just mentioned is this. We are not primarily concerned with the motion of the electron in the atom; what we want to account for, first of all, is the radiation that goes out from it. Therefore, now that we encounter so many difficulties, had we not better refrain entirely from examining the motion of the electron; could we not try, by some direct method of calculation, to deduce the emitted frequencies from e, m and h? This is what Heisenberg, Born, Jordan, Dirac and others attempt to do and in which they have had a success that is very promising. They have established rules of calculation which really lead to the Balmer lines and which can be usefully applied to many other problems. Moreover, these

rules teach us something about the relative intensities of the lines, a point about which it would be very difficult to draw some information from, for instance, the old theory of vibrating particles.

So this matrix dynamics well deserves the attention that is now given it on many sides, the more so because in some cases, in which it does not lead to the same consequences as Bohr's theory, observation appears to be in favour of it. It can, however, not be denied that, with regard to the question *how* atoms radiate, we are almost farther from a solution than we were with Bohr's theory; from the outset the question is purposely avoided, because it is considered as lying beyond what we can know, or want to know.

On the other hand, the last of the theories on my list, tries again to give us a picture of the mechanism of radiation. It was originated by Louis de Broglie, who, some years ago, made an ingenious attempt somewhat better to understand Bohr's quantum condition. According to his views the motion of the electron in a circle is accompanied by a progression of some kind of waves along that line. The frequency of these waves is the one that corresponds to the energy which we attribute to the electron, and the waves are supposed to have a certain velocity, not equal to that of the electron, but closely connected with it, the relation between the two velocities being as could be reasonably expected. Dividing the velocity of the waves by their frequency one finds the wave-length, i.e. the distance over which one must go forward in the direction of propagation to come back to the same phase of vibration. Now, it is clear that, when the waves are propagated along a circle, it is necessary that, at a chosen point of that line, one should find but one phase and not two different ones. This gives us the condition that the circumference of the circle must be just a wave-length or a certain number of full wave-lengths. When this is worked out one finds exactly the quantum condition of Bohr's theory.

Stimulated by de Broglie's ideas, Schrödinger has further developed this "wave mechanics." The electron in the hy-

drogen atom now disappears from the stage; it is replaced by something that is distributed all over the space surrounding the nucleus, though its density, if I may so call it, rapidly diminishes as the distance from the nucleus increases. This "atmosphere" can be the seat of certain changes comparable with wave motions which Schrödinger determines by means of a properly chosen equation; he calls this the wave equation. From it he deduces numbers equal to the values of the energy in Bohr's stationary states. Furthermore he has been able to assign to any point of the atmosphere a certain quantity which may be considered as the density of an electric charge. Its values are such that the total charge is equal to that which formerly was attributed to the electron, so that now, at distant points, the action of the nucleus is neutralized by that of the atmosphere. Finally, the wave equation shows that there can be cases in which the distribution of electric charge is not invariable but fluctuates periodically with a frequency just equal to that of the radiations emitted by the atom. These fluctuations can give rise to electromagnetic waves much like those which we produced by the motion of charged bodies. If all this is true we really have here, in a formerly unexpected form what we wanted to attain in the classical theory, a radiation that is the direct consequence of real periodic changes in the atom.

Schrödinger's theory has a great beauty and I fear I did but poor justice to it in my attempt to present part of it in plain words. By a curious coincidence it is in many respects mathematically equivalent to the dynamics of matrices so that in their further development the two theories have many times gone side by side. Schrödinger has developed his ideas to a considerable extent and has applied them to many interesting questions. Yet, with all due appreciation, I must lay stress upon some outstanding difficulties, which, I must not forget to add this, Schrödinger himself perfectly realizes. The first is this. The wave equation expresses the influence which, in virtue of its electric charge, the nucleus has on the changes going on in the atmosphere. Now, since the charge

distributed over the atmosphere is of the same nature as that of the nucleus, only with the opposite sign, and as similar actions go out from it, because at a distant point, it counterbalances the force exerted by the nucleus, we should expect some mutual action between the different parts of the atmosphere, one part having, by its charge, an influence on what takes place in the other part. These mutual actions, however, have been formally excluded. If we took them into account, we should no longer find Balmer's series.

Doubts may also be raised as to the spreading out of the charge of the electron over a space of the dimensions of the atom. A distribution of this kind, could, if it existed, be hardly limited to the hydrogen atom. Now, there are many cases in which a charge can be removed from an atom and in which after its expulsion it behaves as the ordinary free electrons. It would therefore become necessary to assume that, according to circumstances, the charge may be either concentrated in the shape of an electron, or much more widely diffused.

I need scarcely add that in making these remarks I do not in the least mean to disparage the value of the new theories from whose further development certainly much may be hoped.

Gravimetric Determination of Potassium as Potassium Perchlorate.—J. P. MEHLIG of the Oregon State Agricultural College (Jour. Chem. Education, 1927, *4*, 1537–1543) recommends the gravimetric determination of potassium as potassium perchlorate. The method is very economical, very easily carried out, sufficiently accurate for all industrial analyses, gives good results in the hands of beginners, and may readily be applied to soils. The results compare very favorably with those obtained by the chloroplatinate method. Recovery of platinum is eliminated; and soils may be fused in silica crucibles. J. S. H.

Behavior of the Anthocyan Pigments in Canning.—CHARLES W. CULPEPPER and JOSEPH S. CALDWELL of the U. S. Bureau of Plant Industry (*Jour. Agric. Research*, 1927, *35*, 107–132) have made an exhaustive study of the violet, pink, or purple discoloration which occurs when certain fruits and vegetables are canned in tin. With some materials, the discoloration occurs regularly and is accepted as a matter of course. With other materials, the discoloration is occasional and sporadic, causes rejection of the product as unfit for food, and thus gives rise to economic loss. The discoloration occurs in tin cans, either plain or enameled, but not in glass containers. The discoloration develops only in vegetables and fruits, which contain red anthocyan pigments, as a result of a reaction between the pigment and tin dissolved from the can, with the formation of a violet complex metallic compound of anthocyan. The formation of this compound is favored by a low acidity of the medium, and is retarded or prevented by a high acidity. Use of enameled cans tends to reduce discoloration and preserve the original color of red fruits, but also tends to favor perforation of the container by limiting the area of metal attacked by the fruit acids. Every substance canned presents a specific problem. J. S. H.

A FEW REMARKS ON THE PROBLEM OF THE RECOMBINATION OF POSITIVE IONS AND ELECTRONS.*

BY

DR. J. FRANCK

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THE problem of the recombination of positive ions and electrons has in the past been studied chiefly by optical methods. The authors of these researches investigated the behavior of the continuous spectrum at the end of the atomic series under various conditions. The conclusion which they arrived at from this work was that the continuous spectrum is emitted with a sufficiently great intensity to enable the spectrum to be observed, provided the density of slowly moving positive ions and electrons is great enough.

In the first part of this paper I wish to raise the question as to whether it is possible that such a continuous spectrum at the end of a series can also be emitted under conditions by which normally a recombination of free positive ions and electrons does not occur.

I propose to discuss this question by advancing the hypothesis that this continuous spectrum at the end of the series may also be emitted by a process which I shall term *initial* recombination. This process may be described as consisting of a recombination between an ion and its *own* electron under conditions such that the electron is never really free. Such an hypothesis makes it possible to understand some features of the intensity of light emission among arc lines as a function of the velocity of the electrons which excite the atoms.

The excitation probability of quantum transitions has a large value for two regions of kinetic energy of the bombarding electrons. One region has been investigated by the method of electron impacts and lies in the neighborhood of the

* Presented at the Conference at the Loomis Laboratories in honor of Prof. Franck, January 6, 1928.

minimum excitation potential of the electrons. We know that in this region the probability of a given transition rises from a threshold value to a maximum in the neighborhood of this threshold and then rapidly falls to small values. For instance, let us consider the excitation of the line 2,537 Å. in mercury. The emission begins at 4.9 volts. The maximum is in the neighborhood of six volts and with 15–20 volts the intensity is weak. If we compare a transition which is an allowed transition in the case of light absorption with a transition which is forbidden according to the correspondence principle, we find that the forbidden transition takes place in the case of electron impact with a yield which is much smaller than that for the allowed transition; while the region of kinetic energy of electrons in which the probability of excitation is different from zero is much smaller than in the former case. According to the correspondence principle we should expect such a behavior.

The other region of energy where the probability of excitation is great is one with much greater electron velocities (50–300 volts). In these the intensity of the excitation of arc spectra is great and this part of the so-called "anregungsfunktion" is not related to the low voltage portion discussed above. The intensity at higher velocities is much greater than we would expect from an extrapolation of the lower velocity curve, and the difference between allowed and forbidden transitions vanishes. For instance, Dymond, using impacts of electrons from 100–1,000 volts, studied the intensity of the orthohelium and parhelium spectrum and found that both have nearly the same intensity. This is not in agreement with the behavior noted above for slowly moving electrons. The normal state of helium is the parhelium state and therefore transitions to orthohelium which are not allowed by the correspondence principle should occur with a much lower probability.

One would naturally try to explain light emission in this case as before, by making the assumption that recombination is responsible. Seeliger, who studied the excitation of spectra

by more rapidly moving electrons in the negative glow in the neighborhood of the cathode in an electric discharge, also came to the conclusion that recombination is after ionization by rapidly moving electrons the source of light emission. If we make this assumption it is to be expected that the intensity of light will be greater with the voltage which gives a greater number of ionizing processes, which is in a measure true. Furthermore this explains the observed result that parhelium and orthohelium have nearly the same intensity, since with recombination the probability of building a parhelium atom or an orthohelium atom should be practically the same.

The explanation of these phenomena on the basis of recombination, however, presents one serious difficulty. This difficulty arises from the fact that the intensity of light emission is apparently uninfluenced by applied electric fields which should be great enough to prevent normal recombination. Moreover if we observe the behavior of a bundle of cathode rays in a gas at low pressure, we notice that the light emission takes place practically only within the sharply defined path of the electrons themselves and not in the region surrounding this beam in which the number of electrons and ions is practically the same as in the beam itself, as a result of diffusion processes. The difficulty disappears if we make use of the hypothesis of an *initial* recombination. We should, with such a process, expect this *initial* recombination to have a probability which has the same order of magnitude as a normal recombination and to be relatively little influenced by external fields. In the case of a normal recombination an electron which enters into the sphere of influence of the positive ion has the possibility of emitting light by the acceleration which takes place under the influence of the positive charge of the ion. If the quantum $h\nu$ which is emitted is sufficient, then the transition from an open orbit to a closed orbit takes place. If we study ionization processes by light absorption or by electron impact, each electron which is expelled from the atom has to go through this area of influence of the positive ion. The difference from normal

recombination is that in this case the actual acceleration by the positive ion has a negative sign. Therefore we should expect that the electrons which originally received an amount of energy which is large enough to enable them to leave the ion may in some cases be recaught before the escape. Under these conditions the first act is the transfer of energy to an atom sufficient to ionize the atom. The second process is emission of one of the frequencies which belong to the continuous spectrum at the end of the series, due to the return of the electron which started to leave the atom to its parent atom by an *initial* recombination to one of the outer orbits. The result is an atom which is more or less excited and emits spectral lines of the arc. The influence of an outer electric field under these conditions would be comparatively small, because the electron does not describe a whole mean free path in which it is accelerated by the outer electric field, but it is always under the influence of the intense field of the positive ion. It would be interesting to test the hypothesis by studying the intensity of the continuous spectra emitted under conditions under which normal recombination does not take place. Experiments which we have undertaken during the last month in our laboratory have up to the present time not yielded a positive result. It seems that the experimental conditions were not yet good enough to give a sufficiently great intensity of spectral emission.

Another point to which I wish to refer also deals with recombination. Recombination can take place between an electron and an ion under conditions where either the electron loses energy by radiation, which is the case we considered in the first part of the article, or through loss of energy of the electron by a triple impact between a positive ion and two electrons, in which the surplus energy of the one electron is communicated by some process to the other electron, which therefore gains energy. It is the process of the recombination through triple impact which I am going to discuss. This process, as is very well known, is the reverse of the process of ionization by electron impact. According to a principle first

proposed by Klein and Rosseland the recombinations through such a triple impact should occur with the same probability as the ionization by electron impact *when thermal equilibrium exists.* Experimentally this effect has not until now been observed with the experimental arrangements which are used in the laboratory. It seems to me, however, that the existence of this type of recombination and also the occurrence of other triple impacts between electrons and positive ions may be responsible for some very important results recently obtained by Langmuir. Langmuir studied the velocity distribution of a beam of electrons which passes through a highly ionized gas at low pressure. He found that the velocity distribution of these electrons is changed in such a manner that a Maxwellian distribution is superimposed on the velocity distribution which is present in the absence of the highly ionized gas. The amount of energy which these so-called primary electrons receive and lose becomes very high when the conditions are properly chosen. For instance, a beam of 200 volt rays shows a velocity distribution in which electrons with a velocity of 250 volts or more occur, while on the other hand electrons with 100–150 volts velocity are also present. The great majority of the electrons change their velocity by small amounts but each electron has its velocity really changed. This presents a difficulty in that this process takes place under conditions for which the mean free path of the electrons in the non-ionized gas is much larger than the diameter of the discharge bulb. Several attempts to give an explanation of this effect through the assumption of electrical oscillations or by fluctuations of space charge are not in accordance with the results of Langmuir. If we wish to explain these results by the assumption of triple impacts, we must bear in mind that triple impacts between the primary electrons, ions and the very slowly moving electrons found throughout the volume (Langmuir's ultimate electrons) cannot be responsible for this effect. For beside the necessity of having an appreciable velocity in order to enter into the interaction in triple impacts we have experimental evidence

for this statement. If two parallel beams of primary electrons of different velocities are produced in a bulb, we find that unless the two beams are very close together the velocity distribution in one does not influence that in the other. Since the only electrons diffusing over large distances are the ultimate electrons, it is seen that the changes in velocity distribution cannot be caused by these. On close approach of the beams, however, electrons of higher velocities go from one beam to the other so that the distributions in each beam influence the other. Thus the triple impacts which are to explain these experiments must be those between primary electrons, faster secondary electrons and ions. The secondary electrons have a velocity which is much greater than that of the ultimate electrons. They are generated in ionizing impacts of primary electrons and atoms and preserve their energy only in the neighborhood of the path of the primary rays. The triple impact between such secondary electrons, the primary electrons and an ion is just the reverse of an ionizing process which largely accounts for the larger energy losses of primary electrons. In the triple impact of this type, if recombination results, the primary electron leaves with an energy greater than it originally had, and one has an excited atom. The transfers involving larger energy changes can occur only if the three bodies come within a relatively small distance of each other, and they should accordingly be relatively rare. As a matter of fact, the abnormally high velocities observed by Langmuir are infrequent compared to the exchanges involving small energy losses. The greater proportion of the primary electrons suffer small alterations of energy. So far as these alterations are gains of energy the process which takes place must be a triple impact between primary electrons, secondary electrons and an ion in which the secondary electron does not combine with the ion but suffers only a small energy loss which is gained by the primary. Smaller and greater energy losses we need only consider ionization processes of normal and excited atoms. The higher the degree of excitation the greater the effective radius of the atom and the more frequent and smaller the energy losses.

Provided that the hypothesis that triple impacts are responsible for the phenomena proves tenable, then Langmuir's method of studying the velocity distribution should determine the yield of these triple impacts. This is of great importance not only for the questions of the discharge of electricity through gases, but also for astrophysical questions. This paper will be published in greater detail in the *Zeitschrift für Physik*.

A Case of Double Reflexion. E. T. S. APPLEYARD and H. W. B. SKINNER. (*Proc. Cambridge Phil. Soc.*, Vol. 23, Pt. 8.) An isosceles right-angled quartz prism was made, the optical axis of the quartz being perpendicular to one of the short sides adjacent to the right angle. "The prism has the property that it gives two images when light enters perpendicular to one of the faces and, after internal reflexion at the hypotenuse, passes out at right angles to the other face." Both the incident and the emergent rays would seem to meet the quartz surfaces at right angles and there is no double refraction because the crystal is uniaxial. "The effect was due to double reflexion at the hypotenuse of the prism. In the case of ordinary reflexion, for example from a glass surface in air, the equality of the angles of incidence and reflexion depends on the equality of the velocities of light before and after reflexion. In the case of the quartz prism, for the ordinary ray these two velocities are equal; for the extraordinary ray they are not, since before reflexion the light is going (for instance) parallel to the optic axis and after reflexion perpendicular to it. Thus there are two reflected rays; for one the angle of incidence is equal to the angle of reflexion, but for the other it is not." The angular separation of the two reflected rays is only about 1/3 of a degree. It makes no difference whether the light enters the prism in the direction parallel to the axis or perpendicular to it. The authors have not succeeded in finding any reference in standard works to the effect that they have explained.

Owing to the rotation of the plane of polarization by the crystal the condition of the two emergent rays in respect to polarization depends upon which of the two equal sides of the prism the incident light fell. If it entered parallel to the optical axis the two images seen are completely polarized. If it entered perpendicular to the axis both images are "more or less unpolarized."

G. F. S.

NEW EFFECTS IN THE OPTICAL EXCITATION OF VAPORS.*

BY

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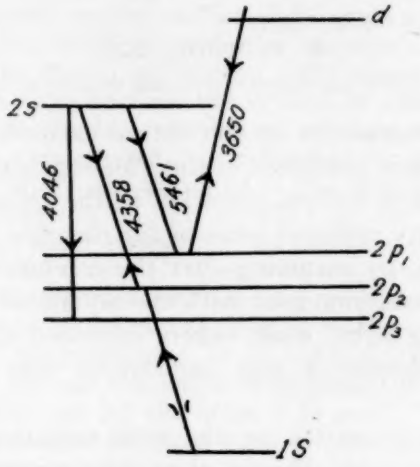
IN a communication on the optical excitation of mercury vapor, which was published in the *Philosophical Magazine* for September, 1927, I drew attention to the circumstance that certain intensity ratios of some of the mercury lines could be explained only by assuming that the intensities of some of the emitted lines increased with the square of the intensity of the exciting light, while others increased with the cube. The reasonableness of this assumption was explained as follows:

The vapor is excited by the total radiation of a water-cooled mercury arc. By the absorption of the radiation of wave-length 2,536 the normal mercury atoms are brought into the excited state with electrons on the $2p_2$ energy level (or orbit). These atoms are in a condition to absorb the 4,358 radiation, by which process they are brought into a higher excited state, the electrons being raised to the $2s$ level. From this level they may return to the lower levels $2p_1$, $2p_2$, $2p_3$, with the emission of the lines 5,461, 4,358 and 4,046. The atoms which were responsible for the emission of the green line 5,461 are now in the meta-stable condition with electrons on $2p_1$, and can absorb the radiations 3,650, by which they are brought to a still higher excited state with electrons on the d orbit. From this level the only transition which can take place is a return of the electrons to $2p_1$, with emission of the line 3,650, and this is the only way in which this line can be optically excited. These transitions are shown in

* Presented at the Conference at the Loomis Laboratories, in honor of Professor J. Franck, January 6, 1928.

Fig. 1, upward pointing arrow indicating absorption; downward pointing, emission. Suppose now we double the intensity of the exciting light by bringing the mercury arc nearer to the resonance tube. Twice as many normal atoms

FIG. 1.



are brought into the excited condition $2p_2$, and are acted upon by radiations of wave-length 4,358 of twice as great intensity as in the first case. Consequently the emission of lines resulting from the two successive absorptions will be four times as great as in the first instance, while the 3,650 line, which results from three successive absorptions, will be increased eightfold. We thus have a medium of which the luminosity (for a single color) increases with the cube of the intensity of the light which illuminates it.

During the past autumn, Dr. Gaviola and I have been investigating the matter quantitatively. As in the earlier experiments, the mercury vapor was contained in a vertical tube of fused quartz surmounted by a right angle prism of quartz which reflected the fluorescent light into the spectrograph. The tube was at room temperature and was highly exhausted, or filled with nitrogen at a pressure of a millimeter or two, by which the intensity of the fluorescent light is

enormously enhanced, for reasons given in my earlier papers. The quartz mercury arc was mounted alongside of, and close to, this tube. It is obvious, as I pointed out in the earlier paper, that we must not change the intensity of the exciting light by a rotating sector, as is commonly done in photometry, as this causes merely a series of successive flashes of light of the original intensity, separated by dark intervals. We must actually change the intensity, either by altering the distance of the lamp from the resonance tube or by introducing between them an absorbing screen, capable of absorbing radiations of all wave-lengths to an equal degree, a wire gauze for example.

A very convincing method of showing the abnormal enhancement of the fluorescence with increase of the intensity of the exciting light was the following. A square of wire gauze of rather fine mesh was held between the resonance tube and the eye (which viewed the interior "end-on" through the prism). The green fluorescence was reduced to 1/5th of its original intensity by the gauze, but was still bright enough to be very conspicuous. The wire gauze was now held between the arc and the resonance tube, and the luminosity of the vapor was no longer seen, having been reduced to 1/25th of its initial value, with the screen in this position. We have photographed the various lines of the spectrum of the optically excited vapor, with and without the gauze screen between the lamp and the tube, and made photometric comparisons of the intensities of the lines, verifying the prediction that lines resulting from a two-stage absorption increased with the square of the intensity of the exciting light, while those which resulted from a three-stage absorption increased with the cube.

A second problem upon which we have been engaged has to do with the effects of other vapors or gases on the emission of the light. I have shown in earlier papers that the presence of a trace of nitrogen in the tube brings electrons from the $2p_2$ level to the $2p_3$ meta-stable level, the atoms now being in a condition to absorb the 4,046 radiations. This results in

an enormous enhancement of the fluorescent light. If the resonance tube has not been de-gassed or contains a trace of water-vapor, the so-called "water bands" (now ascribed however to HO) appear as well as the mercury lines, and the "forbidden line" 2,655.8, due to a transition from $2p_3$ to $1S$, appears with an intensity equal to that of the neighboring lines 2,652, 2,654 and 2,655.

Dr. Gaviola and I have looked into this matter more carefully, introducing measured amounts of water vapor, nitrogen and air, the air being introduced to furnish oxygen to combine with the hydrogen set free by the dissociation of the water-vapor into H and HO. This was found to increase the intensity considerably, since hydrogen is the most detrimental to fluorescence of all of the gases. The results obtained were too numerous and varied to go into here, the one of greatest interest, however, being the one dealing with appearance of the "forbidden line." It appears that both water-vapor and nitrogen must be present, the nitrogen bringing electrons to $2p_3$ on a very large number of atoms. Their return from this level to the normal level $1S$ is greatly facilitated by the presence of water-vapor, though the reason for this is still obscure.

Dr. Gaviola has made a number of interesting calculations from our observations, and I will now ask him to say a few words regarding them after which, with your permission, I will resume my narrative.

Dr. E. Gaviola: Professor Wood has already published, in the *Phil. Mag.*, September, 1927, that the anomalous behavior of the line 3650 in the fluorescence light of a quartz tube containing mercury vapor at room temperature and illuminated by a mercury arc was mainly due to the fact that the emission of 3650 requires three successive absorptions, and that therefore its intensity must be proportional to the cube of the intensity of the exciting light. We have been able to measure a 1200 times increase of 3650, increasing the intensity of the arc only about 11 times. That law seems to conflict with the principle of conservation of energy. The question arising

is this: If we increase the arc intensity 100 times, will 3650 increase a million times? And if so, where will the energy come from? The answer is that 3650 will increase a million times in the volume elements of the fluorescent vapor where the three successively absorbed lines really increase a hundred times. That will generally not occur in the interior of the vapor because of the special absorption laws for 4358 and 3650.

Let us consider a volume element v of the fluorescent vapor at the distance x from the wall where the exciting light enters, which we will assume is parallel. We will designate the intensity of the fluorescent light of wave-length 3650 at distance x from the entrance window by i_x 3650, and the intensity of 3650 in the exciting beam at the same point by I_x 3650. The intensity i_x 3650 of the line 3650 emitted by that volume element will be proportional to the number of atoms in the level d that are present in that volume element. That number which we will designate by $n_x d$ will be proportional to the number of atoms in the level $2p_1$ multiplied with the intensity I_x 3650 of the line 3650 of the arc at the volume element v. In the same way $n_x\ 2p_1$ is proportional to $n_x\ 2s$, since atoms on the $2s$ level become $2p_1$ atoms by the emission of the green line, and $n_x\ 2s$ is proportional to $n_x\ 2p_2$ times I_x 4358. Finally, $n_x\ 2p_2$ is proportional to N, the number of atoms in the normal state, multiplied by I_x 2536.

We thus have

$$i_x\ 3650 = a \cdot I_x\ 2536 \cdot I_x\ 4358 \cdot I_x\ 3650,$$

in which a is a constant. To know how the fluorescence line 3650 changes with the arc intensity and with the position of the volume element v, we require the absorption laws of the arc lines in the especial case here concerned. The absorption law for 2536 is as commonly

$$I_x\ 2536 = I_0\ 2536 \cdot e^{-\gamma x},$$

where I_0 2536 is the intensity of that line at the entrance wall

of the tube. For 4358 and 3650 the absorption laws are different, due to the fact that the density of the gas formed by the excited atoms able to absorb those lines is not constant along the cross section of the tube. An elementary calculation shows that

$$I_x\,4358 = I_0\,4358 \cdot e^{-\frac{a}{\gamma}(I_0\,2536 - I_x\,2536)}$$

and

$$I_x\,3650 = I_0\,3650 \cdot e^{-\omega(I_0\,4358 - I_x\,4358)}.$$

Introducing these values above, we have that

$$i_x\,3650 = a \cdot I_0\,2536 \cdot I_0\,4358 \times I_0\,3650 \cdot e^{-\gamma x} \cdot e^{-\frac{a}{\gamma}(I_0 2536 - I_x 2536)}\; e^{-\omega(I_0\,4358 - I_x\,4358)}.$$

In the case of mercury vapor at room temperature the last two factors of the formula are practically constant and equal to one because of the faint absorption of 4358 and 3650. The intensity distribution of 3650 will be given by the absorption law of the resonance line 2536. As long as that is true, the intensity of 3650 will increase with the cube of the arc intensity in every element of the resonance tube. If the intensity of the arc is continually increased, the last two factors will begin to make themselves noticeable and to take forms more or less similar to exponential falling curves. i_x 3650 will then be proportional to the product of three more or less exponential falling curves and a further increase of the arc intensity will increase it only in the first layer of atoms at the entrance wall of the resonance tube, and will eventually decrease it in the interior of the tube. In brief, the volume fluorescence of the line 3650 will become more and more surface fluorescence.

Professor Wood: I should next like to bring to your attention some experiments which I have been making in collaboration with Dr. Vivian Voss of the University of Pretoria, South Africa, who is with us this morning.

There has been a discussion recently in regard to the green fluorescence of mercury vapor excited by the light of

the spark between terminals of aluminium, cadmium, zinc, etc. This is a quite different phenomenon from that which we have just been considering, as it results from the absorption of light in the region of the absorption bands of the mercury *molecules*, which begin to appear in the vapor when it attains the pressure associated with a temperature of 200° or thereabouts. I have, for a long time, maintained that this fluorescence resulted only when the vapor was distilling, the inference being that some of the mercury vaporized as molecules, which were rapidly dissociated into atoms. This observation has been confirmed by others, both for mercury and cadmium. The most conclusive proof of this appeared to be an arrangement which I employed in an investigation carried out in collaboration with J. S. Van der Lingen many years ago. Two small quartz bulbs joined by a short tube were highly exhausted and sealed, a small drop of mercury having been introduced previously. The double bulb was mounted in the column of hot air rising from an asbestos chimney supported about a nest of bunsen burners. At a temperature around 250° the phenomena in question were well seen. One bulb was always slightly cooler than the other, by perhaps 5 degrees. In this the unvaporized mercury collected. An aluminium spark was mounted close to the bulbs, and no trace of fluorescence was observed, though both bulbs contained mercury vapor at the pressure corresponding to the temperature of the cooler bulb. If now a stream of cold air was directed against the hotter bulb by blowing through a small tube, the other bulb, in which the mercury had collected, immediately showed a brilliant green fluorescence, which persisted until the last trace of liquid mercury had disappeared, when all fluorescence ceased. The air blast was now stopped, and in a few seconds the other bulb burst into fluorescence, no fluorescence ever being visible in the bulb into which the mercury was distilling. Though I had at times observed fluorescence in what *appeared* to be stagnant vapor, I felt inclined to assume that in these cases *some* distillation was going on, and regarded the experiment

outlined above as practically conclusive. Quite recently, however, Niewodininzanski has published results announcing fluorescence in bulbs containing no *fluid* mercury at all, and claiming that distillation had nothing to do with the phenomenon. He apparently did not repeat our experiment with the double bulb, and offered no explanation of the result. Evidently there was room for further investigation, and the matter now appears to be cleared up in a very satisfactory manner, for it appears that everybody was right. Distillation is necessary under certain conditions, and we have found out what these conditions are, for we have prepared a single sealed quartz bulb which can be brought into the condition in which it will fluoresce at constant temperature, or by a simple treatment will fluoresce only when a stream of cold air is suddenly directed against the side away from the layer of mercury droplets. We prepared a single bulb which showed fluorescence only when distillation occurred, but having previously prepared one which fluoresced with stagnant vapor (this one well de-gassed by long heating), it seemed probable that the former might contain traces of air or water vapor. To test this we mounted the bulb between two small brass plates attached to a high frequency oscillator giving continuous undamped oscillations of about 3 meters wavelength. A blue glow appeared in the bulb and we photographed the spectrum to determine whether anything other than mercury vapor was present. After half an hour or so, the luminous discharge ceased. We now found that the bulb, which previously showed fluorescence only with an air blast, now showed it at constant temperature without distillation. A small pointed gas flame was now directed against the bulb, heating one-half of it to a red heat, after which it was again examined. *It was now found to be in its original condition, fluorescing only with an air blast.* On again subjecting it to the high frequency electric field we again brought it into the other condition, and we carried it back and forth from one condition to the other a large number of times. The high frequency field evidently drove the gas contamina-

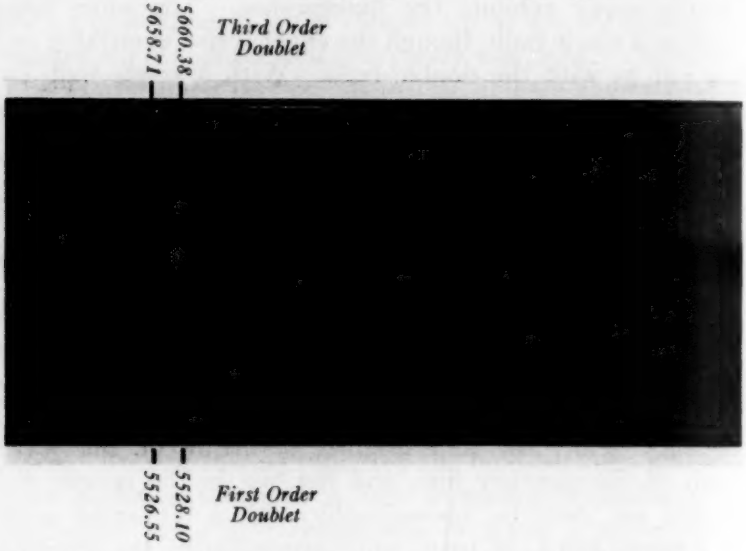
tions into the quartz, from which they were driven out by the superheating with the small flame. The action taking place in the double bulb, or the single one for that matter, is as follows. The bulb contains a trace of water-vapor at very low pressure which destroys the fluorescence. As soon as distillation begins, the freshly formed mercury vapor drives the contaminations over into the other bulb, and the pure mercury vapor exhibits the fluorescence. The same thing occurs in a single bulb, though the effect is not as striking and clear cut as with the double bulb. With a single bulb the contaminations are more or less pressed back against the cooler wall by the rapidly vaporizing mercury.

The third topic which I wish to bring to your attention is a very remarkable result which has just been obtained with the optical excitation of iodine vapor in helium at a pressure of half a millimeter or so.

As I showed many years ago, if iodine vapor in vacuo is excited by a monochromatic radiation, for example, the green mercury line, the vapor emits a series of close doublets, 27 or more in number, spaced at nearly equal distances on a frequency scale, the first doublet occurring at the wave-length of the mercury line, and the last in the remote red, brought out only by photography with a dicyanine plate. Dr. Franck and I, in 1910, while investigating the effects of the presence of inert gases on the intensity of the iodine fluorescence, found that if a little helium was mixed with the iodine vapor the complete band spectrum was developed in addition to the doublets when the excitation was by the green line and two yellow lines of mercury only. Further study, made many years later, showed that the band spectrum appeared with long exposure, even with the iodine in vacuo, and that only certain bands appeared, i.e., the spectrum was simpler than the complete band spectrum excited by white light. During the past year I have been photographing the spectrum developed by helium, with a spectrograph of much higher power, exciting the iodine fluorescence with a battery of four vertical Cooper Hewitt glass mercury lamps which I

built up several years ago for the purpose of obtaining a more powerful excitation of the vapor. The lamps are arranged close together on a single stand, with just room enough between them for the vertical glass tube containing the iodine vapor. They are started by an auxiliary, by simply closing a switch, which is far more convenient than

FIG. 2.



the older arrangement in which the lamp was lighted by tipping. The iodine tubes are about 50 cms. in length by 5 cms. in diameter, blown out at the top in the form of a thin clear bulb, and drawn off obliquely at the bottom, to prevent reflection and secure a good black background. The oblique cone at the bottom is painted black on the outside. With this arrangement I can secure photographs in the second order spectrum of a 6-inch plane grating with a lens of over 3 meters focus in about 15 hours. It was at once apparent from the photographs that something very interesting had developed. In the bands brought out by helium only half as many lines were present as would be found in the corresponding band of the absorption spectrum. *The alternate lines were missing.*

Photographs of the bands in the vicinity of the first and third resonance doublets are reproduced in Fig. 2. Professor F. W. Loomis of New York University has been working with me on the problem, and we find that the rotational quantum number changes by 2, 4, 6, 8, etc., instead of by ± 1, as in the absorption or emission process. This is of great interest in connection with the recent developments in the theory of molecular mechanics dealing with nuclear rotations. I am now going to ask Professor Loomis to give you a short account of the theoretical side of the subject.

Professor F. W. Loomis: With the iodine vapor at a density corresponding to 0° C., and with short exposures, only the "fundamental" series of doublets appear. These are known[1] to be picked out from the complex band spectrum of iodine by the stimulation of one particular iodine absorption line. The absorption of this line leaves all the excited molecules in a single state (^1S, $n' = 26$, $m' = 34$). Each fluorescent doublet then corresponds to the two permitted rotational transitions, $m' - m'' = \pm 1$, which accompany the return to some vibrational level of the lower electronic level (also ^1S).

If, however, the iodine vapor is made denser, or if helium is present at, say, 1/2 mm. pressure, then it is possible for an iodine molecule, while it is in the excited state, to collide with a molecule of helium or of iodine. Excited molecules which suffer collisions of this kind will, in general, have their rotational and vibrational quantum numbers changed. There will no longer be a single initial state for the emission of the fluorescent light, but a group of vibrational and rotational states clustering about the original one. Consequently, the fluorescent spectrum will correspond to transitions from all these states, and bands will be developed around the fundamental doublets ($n' = 26$), as well as neighboring bands with slightly changed values of n' (24, 25, 27, 28).

An inspection of the new photograph of these bands,

[1] National Research Council, Report on "Molecular Spectra in Gases," Chapter VI.

shown on Fig. 2, brings to light the fact that their lines are more widely spaced than those of the corresponding absorption bands. For instance, only two lines appear between the members of each fundamental doublet, whereas in the same region there are five R and five P branch absorption lines.[2] Actual measurement shows that the fluorescent bands consist of *alternate* lines of each branch of the corresponding absorption bands. That is, whereas each absorption band contains a line on each branch, corresponding to every integral value of m', the fluorescent bands contain only lines corresponding to even values of m' (and hence to odd values of m'', since $m' = m'' \pm 1$).

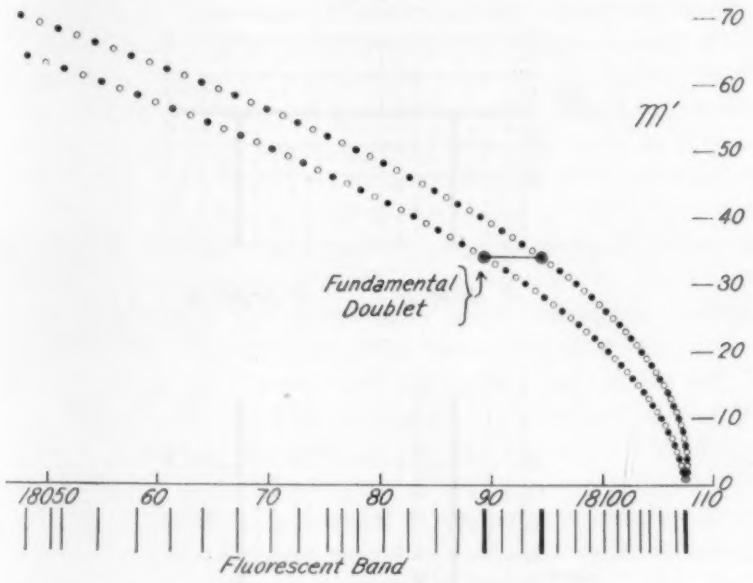
The relation between the two spectra is shown in Fig. 3. The circles represent the absorption lines of band (26, 1). This band happens not to have been measured in absorption, but its lines can be calculated, pretty accurately, from those of other bands which have been measured. The circles representing the lines with even m' are filled in. The measured lines in the optically excited band are indicated below. It will be seen that each optically excited line corresponds to an unresolved pair of absorption lines, say $P(m')$ and $R(m' + 6)$, which happen, in this case, to lie rather close together. There is evidence, on the original plates at least, that these pairs are beginning to be resolved in the case of lines far from the head. Also, there are a few perturbed lines which are clearly resolved. This spectrum will, it is hoped, soon be photographed in a higher order, or with a larger grating, and it should then be easily possible to resolve these pairs.

Possibly the energy level diagram in Fig. 4 will help to make the relationship of these two spectra a little clearer. This diagram shows a few of the rotational levels near those which are associated with a fundamental doublet. The level $m' = 34$, which is the initial level for the emission of the fundamental doublet, is represented by a very heavy line, as are the two transitions from this level, which correspond

[2] "Molecular Spectra in Gases," page 288, Fig. 4.

to the fundamental doublet. The upper levels with even m', which are those having the same character, let us say, for convenience, symmetric, as the level $m' = 34$, are indicated by continuous lines. The lower levels with odd m'' will then also be symmetric and are indicated by continuous lines,

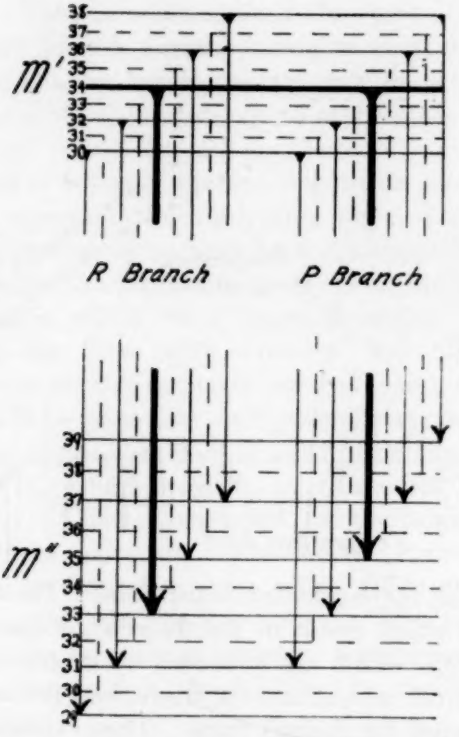
FIG. 3.



and so are the corresponding transitions. These transitions are the ones which result in the fluorescent spectrum. The alternate levels, which are indicated by dashed lines, belong to antisymmetric states, and the transitions between them are also represented by dashed lines. These transitions occur, upward, in absorption because both kinds of states are present in the iodine vapor; but only those represented by continuous lines occur in the fluorescent spectrum because the green mercury arc line happened to be absorbed by, and excite, a molecule in a symmetric state. Of course the words symmetric and antisymmetric can equally well be interchanged in the above statements, as far as we know at present.

No significance is to be attached to the slight systematic shift, in Fig. 1, of the fluorescent lines relative to the absorption ones. It is due merely to inaccuracy in the data used for extrapolation from the measured iodine absorption bands to the (26, 1) band.

FIG. 4.



A few extra lines which do not belong to the (26, 1) band appear in Fig. 3, either interspersed among the lines of the band or as irregularities in the intensity distribution. These are fluorescent doublets, like the fundamental doublets, but due to the stimulation of absorption lines belonging to weak overlapping bands. They are of no interest in this connection. They disappear entirely if the helium pressure is raised to 4 mm.

It is evident, then, that the molecules which are about to emit the fluorescent light occur only in even numbered rotational states. Now the original excited molecule, just after absorbing the light from the mercury arc, and before collision with another molecule, had $m' = 34$. It follows that, *during collisions of the second kind, the rotational quantum number of an iodine molecule can only change by an even number.*

This result, while incomprehensible on the classical Bohr-Lenz theory, is entirely in accord with the conclusions of the new mechanics. According to the theory of Hund,[3] successive rotational states of a symmetrical molecule, such as I_2, have alternately eigen-functions symmetric and anti-symmetric in the positional coördinates of the two nuclei. Moreover, since the symmetric and anti-symmetric eigen-functions correspond to different orientations of the spins of the two nuclei, and since these spins are presumably very completely shielded from outside disturbances, it is to be expected that transitions between symmetric and anti-symmetric states will be very infrequent. In fact, Dennison[4] has recently solved the long outstanding problem of the specific heat of hydrogen by assuming that transitions between symmetric and anti-symmetric states do not occur in appreciable numbers, even during the time it takes to make a measurement of specific heats.

The missing alternate lines in the optically excited iodine bands are then, clearly, direct evidence that transitions between symmetric and anti-symmetric states of iodine molecules do not often occur, even during collisions.

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[3] Hund, *Zeit. f. phys.*, 42, pp. 110–111, 1927.

[4] Dennison, *Proc. Roy. Soc.*, A-115, pp. 483–486 (1927).

Surface Tension of Molten Copper. E. E. LIBMAN. (*Proc. Nat. Acad. Sciences*, Aug., 1927.) No accurate data on the surface tensions of metals are available except for such as can be contained in the liquid state in glass vessels. The author has undertaken to measure the surface tension of liquids that melt above 900° C.

Let us suppose that we have a U-tube of glass, the two communicating tubes being of different diameters. If mercury is introduced, it will not stand at the same level in both tubes but will be lower in the one having the smaller diameter, and will be depressed wherever it comes into contact with the glass. For the experiments with copper is used a crucible of rectangular cross-section having communication near the bottom with a vertical side tube of the same material which has a circular cross-section and is made in the same piece with the main crucible. The metal is melted in this receptacle in a molybdenum-wound electric furnace in which is maintained a vacuum never poorer than 10^{-3} mm. of Hg. The molten copper is in contact with four vertical walls of the crucible and with the periphery of the circular tube. The capillary constant of the liquid can be calculated provided these two distances can be obtained: (1) The difference of level between the surfaces of the liquid in the two communicating tubes, and (2) the vertical height through which the liquid is depressed where it is in contact with a vertical plane surface of the crucible. As the crucible is opaque, recourse is had to X-rays to which it is transparent. A photograph is taken and the required lengths are measured from it. This method applied to mercury gave values of the surface tension in satisfactory agreement with those obtained by other methods.

Measurements of the capillary constant were thus made from the melting point up to about 1,300° for very pure copper and for the same metal containing .04 per cent. SiO_2 and .07 per cent. $Fe_2O_3Al_2O_3$. The capillary constant is directly proportional to the surface tension. For the pure metal the constant decreases from .308 at 1,083° to .297 at 1,318° C. In the case of the impure metal the value at 1,083° is .301 and at 1,335° is .275. As the temperature rises the effect of impurities becomes greater.

G. F. S.

EXTREME ULTRAVIOLET SPECTRA EXCITED BY CONTROLLED ELECTRON IMPACTS.[1]

BY

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AND

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The present investigation is the outgrowth of an unsuccessful attempt to photograph, by ordinary spectroscopic methods, the spectrum of soft X-rays excited in solid targets by the impacts of electrons whose energies are of the order of 100 volts. Numerous experimenters have detected such radiation by photoelectric means,[2] and it is highly important to obtain a direct spectroscopic check on the interpretation of the "breaks" found in their curves of photoelectric current vs. bombarding voltage. It has been assumed that each such "break" indicates the setting in of a new type of characteristic radiation whose frequency is given by the relation $eV = h\nu$. With the best technique which we could muster, and with exposures up to eight days in duration, we failed to obtain any registration of a spectrum on our photographic plates.

Having temporarily abandoned this problem after two years of effort, we have modified our apparatus for use in the study of gases under somewhat different conditions from those hitherto employed. We have simply substituted gas molecules for the solid target previously used, and adjusted conditions so that all radiation from them arises from *single*

[1] Amplification of a paper presented at the Conference at the Loomis Laboratories in honor of Professor J. Franck, on January 6, 1928, by K. T. Compton.

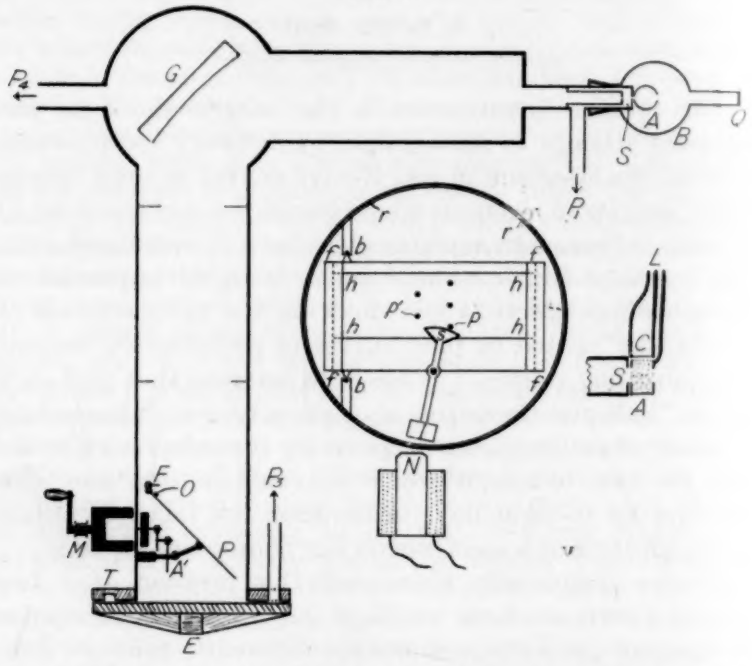
[2] Kurth, *Phys. Rev.*, *18*, 461 (1921); Thomas, *Phys. Rev.*, *26*, 739 (1925); Richardson and Chalklin, *Proc. Roy. Soc. Lon.*, *110*, 247 (1926); Compton and Thomas, *Phys. Rev.*, *28*, 601 (1926), and others.

impacts by electrons of known and controlled velocities. At the same time we have handled the gases in such a manner as to insure so high a degree of purity that there is little room for doubt regarding the origin of the lines appearing in the spectrum.

THE SPECTROGRAPH.

The general plan of the spectrograph is shown in Fig. 1, in which the light source is at A, the grating at G and the

FIG. 1.



photographic plate at P. All are placed within an airtight enclosure consisting of a hollow casting from which the two spectrograph arms, made of seamless brass telescope tubing, extend at right angles to each other. All brass castings are coated externally and internally with solder and the entire enclosure coated externally with enamel varnish and shellac. The apparatus is opened to introduce or remove a plate by removing the brass end plate E. This fits with a carefully

ground and wide surface of contact against the flange on the end of the spectrometer tube, and the joint is rendered airtight by soft wax. In order to eliminate wax vapor from the interior of the spectrometer, and to reduce the danger of leaky joints, a vacuum "guard ring" is provided, as shown at T, through which wax vapor is drawn off by the diffusion pump P_3 through an interposed liquid air trap. The wax is used only on the *outside* of the joint, leaving the ground surfaces in intimate contact. A similar end plate with "vacuum guard ring" is provided on top of the central casting above the grating G. The discharge bulb B is attached to the spectrograph with a ground conical joint, which is also waxed on externally and provided with a "vacuum guard ring."

The four-inch grating G is of glass, 15,000 lines to the inch, for which we are indebted to Professor R. W. Wood of Johns Hopkins University. It is of 1 m. radius of curvature and is used at 45° angle of incidence, so that the two "arms" of the spectrograph are each about 70.8 cm. in length.

The photographic plate P is 4.25 inches long and takes in a range of about 1,200 Å. We have used Hilger-Schumann plates on thin glass, but not thin enough to permit the theoretical bending to 50 cm. radius necessary to secure the best focus over the entire plate. Consequently our focus is a compromise which can be adjusted to give very good focus in any desired region. The method of adjusting the plate deserves mention:

The plate must be inclined at an angle of about 45° with the axis of the tube in order to secure focus over its entire length. It can be tilted through a small range on either side of 45° by an external control as shown, in which the rotation of the external magnet M causes the rotation of the armature on the inside of the spectrograph, and this motion is transmitted through a set of small reducing gears to the pinion A' which controls the tilt of the plate. The zero order line of the spectrum is first brought to a focus at a

point *O* near one end of the plate and in line with the axis of tilting. This can be done without evacuating the spectrograph and with the end plate removed. Then, with the spectrometer evacuated, the spectrum of some gas in *A* is photographed at various angles of tilt, whence the proper tilt can be determined from an examination of the focus in these spectra. The combination of this externally operated tilting device with a similarly operated plate-dropping mechanism enables this whole set of adjustment spectra to be photographed conveniently on one plate.

The plate-dropping mechanism is patterned after one described by Lyman.[3] The plateholder *hhhh* slides up and down in accurate ways in the frame *ffff*, which tilts about the axis *bb* and is secured in position by the pinion *A'*. From the back of the plateholder project two rows of pins *p*. One of these rests against the stop *s* and keeps the plateholder at the desired level for an exposure. When this exposure is completed, the external magnet *N* is moved to the right, attracting with it the iron block *I* which swings the stop *s* to the left, thus releasing the plateholder which drops until pin *p'* rests against the stop *s*, in which position another exposure may be made.

The entire plateholding framework is mounted in a ring *rrr* which slides telescopically in the spectrograph tube and may be moved in or out by a screw in order to adjust the focus of the zero order image.

A new feature has been added in the flapper *F*, which is a stop designed to intercept the light falling at the zero order position on the plate so as to prevent such overexposure of this line that it cannot be used as a point of reference in measurements of the plate. This flapper can be moved in or out of the path of the light by another external magnetic control (not shown). It is found that a one-minute exposure of the zero order line is sufficient even though the remainder of the plate may be exposed for several days.

The slit system *S* is especially designed to permit the

[3] Lyman, "Spectroscopy of Extreme Ultraviolet" (1914), p. 34.

maintenance of a large pressure ratio on its two sides, whereby an excellent vacuum is maintained in the main body of the spectrograph although there is a sufficient pressure of gas in the bulb B containing the light source to permit suitable spectral excitation. To accomplish this, the slit system is double. The first slit (the one nearest the light source) is the spectroscopic slit and is adjusted to a width of about 0.001 cm. One centimeter behind it is a second slit, just enough wider to permit the unobstructed passage of the light from the first slit to the entire surface of the grating G. From between these two slits, gas is pumped away by a rapid diffusion pump P_1. The gas which passes the second slit is pumped away from the main body of the spectrograph by another rapid diffusion pump P_4. In this way a pressure ratio of about 1/250 is maintained between the spectrograph and the light source.

The pumping system is rapid enough and the spectrograph sufficiently airtight to permit evacuation of the spectrograph to $5(10)^{-6}$ mm., as indicated by an ionization gauge. In actual use, however, gas is slowly admitted into the bulb B to maintain in it a pressure of about 0.01 mm. Thus the gas pressure in the spectrograph during operation is about $4(10)^{-5}$ mm.

THE LIGHT SOURCE.

The light source is simply an adaptation of the method which has been so successfully used by Foote and Mohler,[4] Hertz[5] and others to investigate the critical potentials for excitation of spectral lines. Electrons from a Wehnelt cathode C of about 0.7 cm.^{2} area are drawn through an applied potential difference V to the anode A, which is a hollow box covered by a wide-meshed gauze on the end adjacent to the cathode. Within this field-free space, radiation is excited by electron impacts against the molecules. There are two openings at opposite sides of the box, through one of which radiation passes to the slits S and through the

[4] Foote and Mohler, "Origin of Spectra"; Foote, Meggers and Mohler, *Phil. Mag.*, *42*, 1002 (1921).

[5] Hertz, *Zeits. f. Phys.*, *22*, 18 (1924).

other of which radiation passes out through a quartz window Q, and enters a quartz spectrograph which photographs the near-visible spectrum simultaneously with the recording of the extreme ultraviolet spectrum on the plate P. This quartz window is attached to the bulb with a quartz-pyrex graded seal, for which we are indebted to the Cooper-Hewitt Electric Company.

Before its trial, it was a question in our minds whether such a source of radiation (shown in Fig. 1 by the shaded region inside the box A) would be sufficiently intense, in view of the extremes to which other investigators in this field have gone to secure light sources of great energy. Quite to our surprise, the source proved to be very effective. For example, with an electron current of 0.1 ampere in helium at 0.05 mm. pressure an exposure of an hour sufficed to bring out the spark line 303 in three orders and the first few members of the arc series 584, 537, etc., in the first and second orders. To bring out faint lines, we have used exposures as long as 40 hours, which is quite easy because the apparatus runs automatically and without attention.

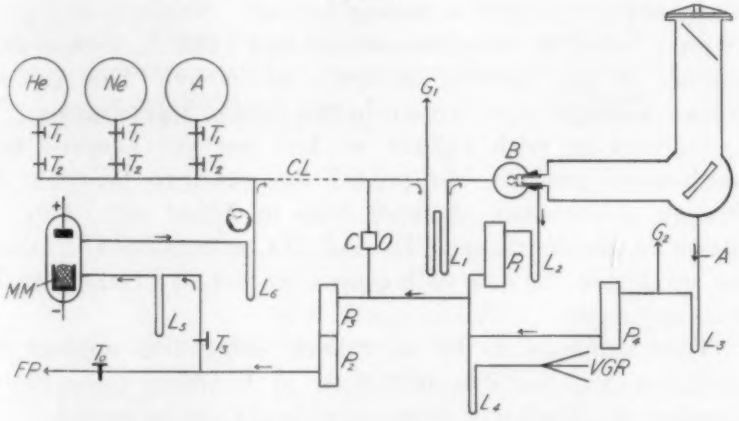
Two spectroscopic peculiarities of this source may be noted. In the first place no cumulative excitation or stripping of atoms by successive ionization is expected, since the current densities are very small and the gas pressure is so low as to make negligible the chance of more than one impact against the same atom. Only effects attributable to *single* electron impacts against molecules are to be expected. This results in a much simpler spectrum, and one easier of interpretation, than in the case of "hot-spark" or arc excitation. In the second place, the spectra due to various degrees of ionization or corresponding to various energies of excitation may be distinguished by exciting the spectrum with different voltages. We find, for example, only helium arc lines at 65 volts, whereas the spark lines are fully developed at 85 volts, which proves, incidentally, the absence of cumulative ionization by which the spark lines would have been excited at 55 volts. Similarly in argon, 30 volts brings out the arc lines but only

faintly some of the strong spark lines of lower excitation energy, whereas 40 volts brings out practically a complete spark spectrum. It is evident, therefore, that voltage control offers an unambiguous method of differentiating between lines of atoms in various stages of ionization.

HANDLING OF GASES.

Naturally, different gases must be handled in different ways, depending on their nature. Thus far we have worked only with helium, neon and argon. In these cases the gases, after extreme purification in an independent purifying system, were placed in reservoirs sealed to the pumping system as shown in Fig. 2.

FIG. 2.



Two stopcocks T_1 and T_2 serve to admit a small amount of gas into the system. This flows through a magnetically controlled capillary leak *CL*, through a double liquid air trap L_1 into the bulb *B* of the spectrograph. The McLeod Gauge G_1 measures the gas pressure in this bulb. This gas ultimately passes through the slits of the spectrograph whence it is pumped, through liquid air traps L_2 and L_3, by two very rapid diffusion pumps P_1 and P_4 which are backed by another two-stage diffusion pump P_2P_3. The vacuum guard rings at the three wax joints, previously mentioned, are pumped into the intermediate stage as shown at *VGR* through liquid

air trap L_4. *CO* is a mercury cut-off which can be opened magnetically to facilitate preliminary evacuation of the bulb and reservoir system, but which is closed during actual operation of the spectrograph.

The gas delivered by the pump P_2P_3 passes through a bulb *MM* which is protected on both sides by liquid air traps L_5 and L_6. In this bulb is maintained an intense glow discharge between a "misch-metal" cathode and an iron anode, which is the most efficient method known for purifying these gases. Therefore the gas is continually repurified before it enters the spectrometer.

In this way we have obtained neon spectra showing all known and many new neon lines without spectral evidence of any impurity except a trace of helium. Similarly in argon, we have found 79 lines between 459 and 1,066 Å., *without any evidence of any spectral impurity whatsoever*. This is, we believe, a unique achievement in this field of spectroscopy.

In working with helium we had not yet adopted the misch-metal purifier, but passed the gas into the bulb *B* through a cocoanut charcoal trap in liquid air. This is known to admit traces of H_2 and CO as impurities, so that our spectra in the case of helium were not so "clean" as in neon and argon.

There appears to be no reason, using this method of excitation and suitable technique in handling gases, why complete elimination of impurities should not be feasible.

Finally a word may be said regarding the source of electrons—the Wehnelt cathode *C*. This was adopted in preference to a tungsten filament in order to avoid use of a bright incandescent filament which might fog the photographic plate by scattered light. With a platinum filament coated with BaO and SrO and operated at a dull red heat, adequate and fairly constant emission could be obtained for a hundred hours or so with exciting voltages up to 100 volts. The spectrum plates showed some fog after 40 hours' exposure, which was probably due to light diffusely scattered from the grating. In any case, 40 or 50 hours appears to be about

the maximum useful exposure time, since longer exposures would probably give sufficient "fog" to diminish rather than increase the sensitivity for detecting faint lines.

SPECTRUM OF HELIUM.

Helium, whose spectrum is so well known through the work of Lyman,[6] was first used to test the action of the spectrograph. As mentioned above, traces of CO and H_2 were known to be present as impurities. Some features of interest are shown by Plates *A*, *B*, *C* and *D*. Tables I, II and III summarize the results and show comparison with other observations. The theoretical values of the wave-lengths of the helium spark lines were used as standards, and

TABLE I.

He II. $1s\ ^2S_1 - mp\ ^2P_2$ (used as standards).

λ (calc. and obs.).		*m*.	(Lyman.[6])	
303.81	(8)	2	303.6	(2)
256.33	(5)	3	256.3	(1)
243.04	(3)	4		
237.34	(2)	5		
234.36	(1)	6		

TABLE II.

He I. $1s\ ^1S_0 - mp\ ^1P_1$.

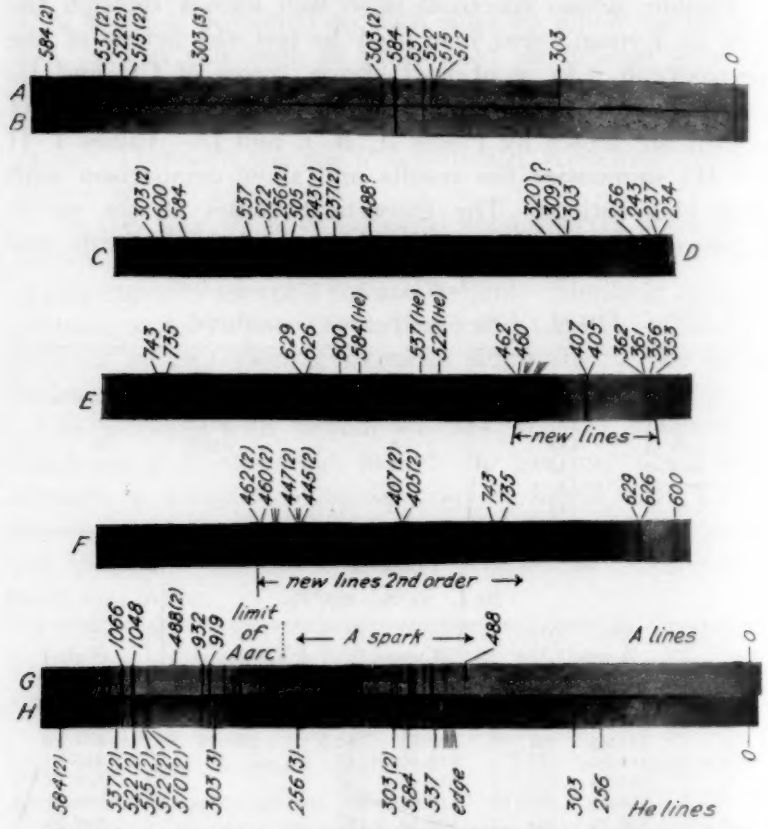
m.	λ (obs.).		(Lyman.[6])		(*D* and *A*.[7])	(Calc.)
2	584.41	(20)	584.40	(10)	584.33	584.44
3	537.04	(10)	537.12	(7)	537.08	537.12
4	522.25	(9)	522.21	(5)	522.17	522.29
5	515.60	(8)	515.56	(4)		515.70
6	512.16	(7)	512.09	(3)		512.18
7	510.02	(6)	510.05	(2)		510.07
8	508.73	(5)	508.59	(1)		508.72
9	507.80	(4)				507.80
10	507.13	(3)				507.13
11	506.65	(2)				506.65
12	Resolvable					506.39
13	but too close					506.07
14	to measure					505.89
15	accurately.					505.77
Edge	504.94					—
∞						504.34

[6] Lyman, *Astrophys. Jour.*, *60*, 1 (1924).

[7] Dorgelo and Abbink, *Zeits. f. Phys.*, *37*, 667 (1926).

should be the best possible standards in this spectral region. The stronger spark lines appeared also in the second and third orders, and thus gave a calibration extending across the entire plate.

PLATES.



(*A*) He at 90 volts; (*B*) He at 70 volts' excitation; (*C*) He arc series; (*D*) He spark series; (*E*) Ne, showing new spark lines in first order; (*F*) Ne, showing new spark lines in second order; (*G*) A at 90 volts; (*H*) A and He at 100 volts.

The calculated values of λ in the last column of Table II were obtained by calculating the convergence wave number of the series by adding to the wave number of an observed line the accurately known term value of the excited state of that line as known from the near-visible series, averaging convergence numbers thus found for all the lines, and then

subtracting the term values of the excited states from this average, to obtain the calculated wave numbers of the lines. The calculated wave-lengths thus determined should make suitable secondary standards of wave-length. The "edge" at 504.94 lies well within the convergence limit 504.34, showing that the continuous band is due to the merging of unresolved higher members of the series rather than to a true continuous spectrum associated with the series limit. This is as expected in view of the fact that our radiation originated in a field-free space where the ion concentration was very small. The continuous band extending beyond the series limit in Lyman's [6] spectrograms is known to be associated with the existence of intense ionic fields or to recombination of ions, or both, within a Paschen cathode.

TABLE III.

(Other lines below 800 Å.)

λ (obs.).	(Lyman.[6])	Remarks.
743.75 (2)	743.73	Ne I $2p\ {}^1S_0 - 3s\ {}^3P_1$
735.94 (3)	735.95	Ne I $2p\ {}^1S_0 - 3s\ {}^1P_1$
720.31 (2)		origin unknown
719.08 (1)		origin unknown
629.81 (1)	629.75	Ne I $2p\ {}^1S_0 - 4s\ {}^3P_1$
626.91 (2)	626.91	Ne I $2p\ {}^1S_0 - 4s\ {}^1P_1$
600.16 (2)	600.3 ± .6 (6)	Ne I $2p\ {}^1S_0 - 5s\ {}^1P_1$ or He I $1s\ {}^1S_0 - 2s\ {}^1S_0$
	591.56 (3)	He I $1s\ {}^1S_0 - 2p\ {}^3P_1$
509.43 (2)		origin unknown
448.40 (2d)		origin unknown
320.38 (3)		He I 1s 2s – 2p 2s?
309.04 (1)		He I 1s 2p – 2p 2p?

The lines shown in Table III, other than those due to neon impurity, require some comment. Line 600 has been the subject of some speculation. Lyman [6] suggested that it is a "forbidden" line 1s – 2s of He I. Sommer [8] pointed out that it was of band-like appearance on Lyman's photographs and attributed it to a band of He_2. Dorgelo and Abink [7] showed that its intensity seemed roughly proportional to the amount of neon impurity and suggested that it was the

[8] Sommer, *Proc. Nat. Acad. Sc.*, *13*, 213 (1927).

relatively weak Ne $2p\ {}^1S_0 - 5s\ {}^1P_1$ line excited by collisions of the second kind with metastable helium atoms in the 2^3S state, and strong because the energy of 2^3S helium is so nearly exactly the amount required for exciting this line of neon. Our line shows none of the band-like character suggested by Sommer. It was greatly enhanced by the addition of a further trace of neon. Consequently we incline toward the view of Dorgelo and Abink. However, in Lyman's work the greater electric fields would favor the appearance of forbidden lines, and the use of gas at considerably higher pressure would favor bands. Thus it is possible that there are really two or three causes which independently give radiation near 600, and that experimental conditions determine which cause predominates.

Lyman's line 591.56, another "forbidden" line, is entirely absent from our spectra. This again may be due to the field-free region of excitation.

Lines 320 and 309 may perhaps be due to excitation of both electrons and radiation accompanying the return of one of them to its normal state, as indicated in the table. Their wave-lengths are just about those to be expected from considerations of quantum defect. If this interpretation is correct, a visible line at about 4,834 would be anticipated. We have not verified this point.

There remain four faint lines of unknown origin. They appear definitely not to be known or previously reported. The only known impurity which could have lines of such short wave-length is CO, and this appears not to be the origin since none of the known strong lines of C or O are found. It is possible that vaporized material from the Wehnelt cathode may be responsible for these lines.

SPECTRUM OF NEON.

The most interesting feature of neon is a new group of lines which are entirely absent at 40-volt excitation, weakly developed at 60 volts and strongly developed at 80 volts. This suggests that they are the fundamental lines of Ne II, which is confirmed by an analysis of the spectrum which we

are publishing in *Proc. Nat. Acad. Sc.* in collaboration with Professor H. N. Russell.[9] Lyman and Saunders[10] have already announced that Ne II lines occur in this region, but have not published wave-lengths or examined the spectrum exhaustively. The new lines are given in Table IV, together with their spectroscopic notation.

TABLE IV.

Extreme ultraviolet spectrum of Ne II.

λ.	Int.	ν.	Notation.
462.38	7	216272	$2p\ ^2P_1 - sp^6\ ^2S_1$
460.72	12	217051	$2p\ ^2P_2 - sp^6\ ^2S_1$
456.35	4−	219130	$2p\ ^2P_2 - 3s\ ^4P'_3$
455.27	4	219650	$2p\ ^2P_2 - 3s\ ^4P'_2$
454.68	3	219935	$2p\ ^2P_2 - 3s\ ^4P'_1$
447.83	3	223299	$2p\ ^2P_1 - 3s\ ^2P'_2$
446.60	4	223914	$2p\ ^2P_1 - 3s\ ^2P'_1$
446.26	7	224085	$2p\ ^2P_2 - 3s\ ^2P'_2$
445.05	2	224694	$2p\ ^2P_2 - 3s\ ^2P'_1$
407.17	3	245598	$2p\ ^2P_1 - 3s\ ^2D_2$
405.88	5	246378	$2p\ ^2P_2 - 3s\ ^2D_{32}$
362.55	2	275824	$2p\ ^2P_1 - 3s\ ^2S_1$
361.54	3	276595	$2p\ ^2P_2 - 3s\ ^2S_1$
356.79	2d	280277	$2p\ ^2P_2 - 3d\ ^2D_{32}$
353.01	1d	283278	$2p\ ^2P_2 - 4s\ ^2P'_{21}$

A start at the analysis of Ne II has previously been made by the discovery of multiplets in the visible and near ultraviolet by de Bruin[11] and by Kichlu,[12] making use of wave-lengths given by L. Bloch, E. Bloch and G. Dejardin,[13] and all identified by the appearance of the wave number difference 782 given by the two ionization limits of Ne I. de Bruin classified 34 lines in 5 multiplets of the quartet system. In collaboration with Professor Russell we have classified 203 lines in 59 multiplets in both quartet and doublet systems, and have thus accounted for all the stronger known lines of Ne II. Table V gives the term values of all the states of

[9] Russell, Compton and Boyce, *Proc. Nat. Acad. Sc.* (in print).

[10] Lyman and Saunders, *Proc. Nat. Acad. Sc.*, *12*, 92 (1926).

[11] de Bruin, *Zeits. f. Phys.*, *44*, 157 (1927).

[12] Kichlu, *Proc. Phys. Soc. Lon.*, *39*, 424 (1927).

[13] L. Bloch, E. Bloch and G. Dejardin, *Jour. de Phys.*, *7*, 129 (1926).

TABLE V.

Term Values in Ne II.

Quartets.			Doublets.		
		Diff.			Diff.
			$2p^6$ $^2P_2$	330429	
					782
			$2p^6$ $^2P_1$	329647	
			$2s^2 2p^6$ $^2S_1$	113376	
3s $^4P'_3$	111300.0		3s $^2P'_2$	106343.7	
		518.0			612.2
$^4P'_2$	110782.0		$^2P'_1$	105731.5	
		299.0			
$^4P'_1$	110483.0		$^2D_{32}$	84050	
			$^2S_1$	53828.5	
4s $^4P'_3$	48432.6		4s $^2P'_2$	47108.4	
		376.9			571.9
$^4P'_2$	48055.7		$^2P'_1$	46536.5	
		305.1			
$^4P'_1$	47750.6				
3p $^4S'_2$	77477.5		3p $^2S'_1$	77532.6	
3p $^4P_3$	84238.2		3p $^2P_2$	76266.0	
		222.8			127.0
$^4P_2$	84015.4		$^2P_1$	76139.0	
		182.5			
$^4P_1$	83832.9				
3p $^4D'_4$	81322.6				
		337.6			
$^4D'_3$	80985.0		3p $^2D'_3$	79419.4	
		249.7			511.0
$^4D'_2$	80735.3		$^2D'_2$	78908.4	
		144.0			
$^4D'_1$	80591.3				
3d $^4P'_3$	49259.5		3d $^2P'_2$	49098.6	
		−181.8			−859.0
$^4P'_2$	49441.3		$^2P'_1$	49957.6	
		−221.5			
$^4P'_1$	49662.8				
3d $^4D_4$	51293.5				
		81.0			
$^4D_3$	51212.5		3d $^2D_3$	50161.9	
		106.5			756.8
$^4D_2$	51106.0		$^2D_2$	49405.1	
		98.2			
$^4D_1$	51007.8				
3d $^4F'_5$	50258.4				
		528.1			
$^4F'_4$	49730.3				
		97.6			
$^4F'_3$	49633.7				
		149.4			
$^4F'_2$	49484.3				
4f $^4D'_4$	27602.0				
		15.0			
$^4D'_3$	27587.0				
		58.9			
$^4D'_2$	27528.1				
		86.7			
$^4D'_1$	27441.4				
4f $^4F_5$	27526.7				
		624.4			
$^4F_4$	26902.3				
		296.0			
$^4F_3$	26606.3				
		−315.4			
$^4F_2$	26921.7				
4f x_2	26830.5				

Ne II thus far identified. The assignment of these terms is entirely assured except those attributed to the 4f electron, in which case the reality of the terms is certain but their assignment is only provisional.

FIG. 3.

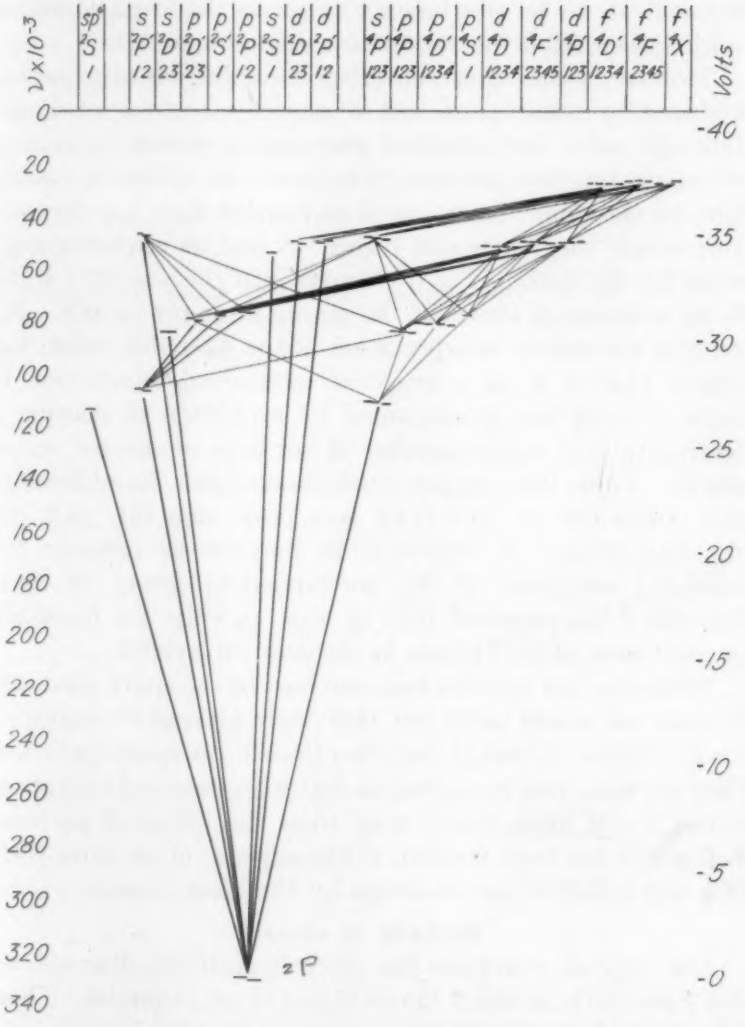


Fig. 3 is a Grotrian diagram of energy levels of the Ne^+ atom. The heavy diagonal lines are the combinations giving the new extreme ultraviolet lines listed in Table IV, while the light diagonal lines are other combinations in the near visible region.

The ionization potential of the neon ion is found from this analysis to be 40.9 ± 0.05 volts, so that 62.4 volts are required for double ionization at a single impact.

Mohler [14] found that photoelectric ionization of neon was produced by radiation excited in neon by electrons of energy above 48 volts, and reported 48.0 and 54.9 volts as critical potentials for this process. The 48.0 volt value is exactly right for the single ionization of an s rather than a p electron, after which the ion would return to one of its low energy states by the falling of a p electron into the vacant s state, giving emission of either of the strong lines 461 or 462. We can give no certain interpretation of the 54.9 volt value, but suggest that it is an average of unresolved effects due to single p ionization accompanied by excitation of another p electron to give one or another of our lines of shorter wavelength. These lines suggest critical potentials, in addition to 48.2 (19) volts, at 49.7 (11), 50.2 (16), 52.0 (8), 55.7 (5), 56.3 (3), where the numbers in parenthesis indicate the estimated intensity of the corresponding group of lines. Dejardin [15] has reported that at least 49 volts are necessary for excitation of Ne II lines in the near ultraviolet.

While the 461 and 462 lines are part of the spark spectrum of neon, we would point out that their process of excitation is not the same as that of the other lines in the spark spectrum. They are more nearly analogous, in their process of excitation, to the X-ray lines, which arise from the filling of an inner shell which has been ionized, at the expense of an outer shell. This was called to our attention by Professor Turner.

SPECTRUM OF ARGON.

Our type of excitation has given beautifully clear spectra of A I and A II, of which Plates G and H are examples. These

[14] Mohler, *Phys. Rev.*, *28*, 46 (1926).
[15] Dejardin, *C. R.*, *182*, 452 (1926).

show many lines of A II not previously reported,[16] and also several new lines of A I near its ionization limit. We are at present engaged in an analysis of the A II spectrum, in collaboration with Professor Russell, and will report it later.

In conclusion we wish to thank Dr. Peter Fireman, of Trenton, N. J., for a gift which made possible the purchase and mounting of the glass grating, and also Professors Russell, Turner and Shenstone for many valuable suggestions. We are also glad to acknowledge the able assistance of Dr. S. Nakamura, who aided us in the design and preliminary adjustment of the spectrograph. Professor Lyman also has kindly advised us on several matters of technique.

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PRINCETON, N. J.

[16] Dorgelo and Abbink, *Zeits. f. Phys.*, *41*, 753 (1927).

The Thermal Conductivities of Certain Liquids. G. W. C. KAYE and W. F. HIGGINS. (*Proc. Roy. Soc.*, A 777.) This paper seeks to extend the range of temperature over which the thermal conductivities of liquids have been measured, and to improve methods of procedure. It comes from the Physics Department, National Physical Laboratory, near London.

When heat traverses a liquid the easiest way to avoid convection currents is to have it flow from above downward. The liquid under experiment was only about .25 to .5 mm. deep and was enclosed between upper and lower blocks of aluminium 5 cm. in diameter. Care was taken to avoid the inclusion of air bubbles between the metal surfaces, and the liquids themselves were heated to remove dissolved air. The aluminium block on which the liquids rested passed on the heat received from above to radiating fins. The block above the liquids was heated by an embedded coil carrying an electric current. The input of power ranged from 3 to 20 watts and the temperature of the hot block from 20° to 200° C. In order to secure the downward flow of all the energy delivered to the hot block precautions were taken to prevent the lateral leakage of heat as well as its transmission upwards. Lateral loss was largely prevented by surrounding the apparatus with asbestos wool and placing it in an enclosure maintained by a thermostat at about the temperature of the hot block. Upward flow of heat was made impossible by putting a guard plate above the hot block and keeping its lower surface at the same temperature as the upper face of the block. Corrections were applied wherever they were needed and the results have high accuracy. In the case of glycerine where the test layer was .0357 cm. deep, its upper surface was at 52.20° C. and its lower at 47.80° C. The total power supplied was 7.574 watts. Of this only 7.202 watts was the rate of flow of heat downward through the liquid. The lateral loss was .246 and the expenditure in evaporating a part of the liquid in this case was zero, while .126 watt went away through excess liquid kept present to assist in filling the space between the two metal blocks.

In water from 0° to 80° C. and in glycerine from 0° to 140° C. the conductivity rises with the temperature, from .00145 to .00160 and from .000673 to .000723 respectively. In the cases of castor oil, olive oil, cylinder, paraffin and transformer oils, the conductivity decreases with elevation of temperature. Aniline does not change.

G. F. S.

THE GREEN AURORAL LINE.*

BY

G. CARIO, Ph.D.

Fellow of the International Education Board.

THE spectrum of the Aurora Borealis has been intensively investigated in the past few years because its analysis affords us information concerning the constitution and state of the upper atmosphere. The most prominent line lies in the visible at 5577·35 Å. McLennan [1] has recently shown that this line is to be ascribed to the oxygen atom. Up to the present time it has been impossible to experimentally excite this green line without causing the appearance of other oxygen lines, whereas in the aurora this line is apparently the only oxygen line obtained, and the light of the night sky shows only this line. Only in the red part of the auroral spectrum may exist some weak lines not discovered hitherto. Is it possible with our present knowledge of the oxygen atom and molecule to explain this state of affairs?

According to Hund's theory the oxygen atom possesses, in addition to the triplet and quintet systems, a singlet system. Hopfield [2] found two singlet lines in the ultraviolet, the frequency difference of which corresponds to the green auroral line. That is to say, the green line is a "forbidden line" and represents a transition of low probability. If we assign these two lines a common upper level, then the excitation potential of the green line would be very small, because the lowest level of the singlet system can lie, at the most, 1 volt above the lowest triplet level. This is shown by the following diagram:

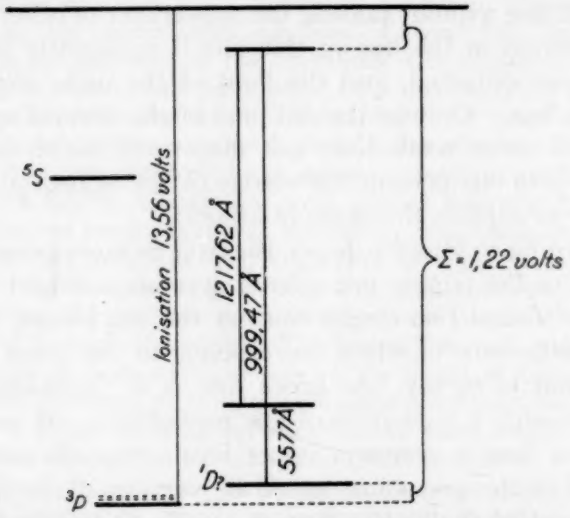
---

* Presented at the Conference at the Loomis Laboratories in honor of Professor J. Franck, January 6, 1928.

[1] McLennan and Shrum, *Roy. Soc. Proc. A.*, 108, 501, 1925.

[2] Hopfield, *Bulletin of the Am. Phys. Soc.*, 2, 28, April 1927.

The green line can only be obtained with reasonable intensity in the discharge tube by the admixture of some argon. The increased intensity of the green line is probably due to collisions of the second kind between excited argon atoms and oxygen atoms in the triplet state, because the argon atoms possess a group of frequent transitions corresponding to 2.9 to 3.1 volts. Mixtures of oxygen with helium and neon were studied by McLennan, who found only a little stronger relative intensity of the green line. My own experiments with mixtures of oxygen with krypton, nitrogen, nitric oxide, and mercury vapor do not result in an increase of the relative intensity of the green line. This type of excitation is however improbable in the upper layers of the atmosphere, due to the absence of argon of such a pressure as is found in the discharge tube.



McLennan[3] has proposed the following hypothesis: That with no other agency than ultraviolet light or electron impact an oxygen molecule may be dissociated into a normal and an excited atom. The excited atom shall be excited to the upper level of the green line transition. In the presence of

[3] J. C. McLennan, R. Ruedi, and J. H. McLeod, *Trans. Roy. Soc. Can.*, 21, 27, 1927.

atomic fields the probability of transitions from the metastable state to the normal state may be increased.

I have considered a somewhat different explanation. A direct dissociation by absorption of light into excited atoms, such as McLennan has suggested, does not seem likely to me, because absorption in the critical region is weak. The interaction of atomic fields seems an unnecessary assumption because forbidden lines simply imply low transition probabilities and if the pressure is very low such rare transitions will not be disturbed by collisions or the like. This same view is shared by Bowen [4] in his theory of the nebular lines. Experiments also to excite pure oxygen with very different electric methods do not result in an increase of the relative intensity of the green line.

I believe that in the upper atmosphere oxygen atoms in the lower singlet state are formed photochemically. Up to the present, only one absorption band of oxygen has been recognized with a convergence limit at 1,750 Å., whence extends a region of continuous absorption in the direction of the shorter wave-lengths possessing a maximum about 1.5–1.8 volts distant from the convergence point toward the shorter wave-lengths. Condon [5] has calculated that this maximum should be about 0.4 volt distant. The difference between these values and the dependences of the band spectrum upon pressure, as observed by Leifson [6] and Hopfield, leads me to believe that a second band system may be concealed in this region. Furthermore, in one of Leifson's photographs a suggestion of maximum 0.4 volt distant from the convergence limit and a suggestion of bands in this vicinity is apparent. That would mean that molecules not only dissociate into atoms in the triplet state, as Birge and Sponer [7] suppose, but also into atoms in the singlet state with 0.5–1.5 volts higher energy than the lowest triplet state. Since the absorption in the postulated band is much greater than in the known band, causing dissociation in triplet atoms, it is easy

[4] Bowen, *Nature*, 1927.

[5] Condon, *Phys. Rev.*, 27, 640, 1926, and 28, 1182, 1926.

[6] Leifson, *Astrophys. Journ.*, 63, 73, 1926.
Hopfield, *Phys. Rev.*, 20, 573, 1922.

[7] Birge and Sponer, *Phys. Rev.*, 28, 260, 1926.

to conceive of the formation of many singlet atoms by solar radiation. In the lower layers of the atmosphere and therefore at higher pressures only longer wave-lengths are effective. The solar radiation is absorbed by the Schumann bands extending from 1,750 Å. to longer wave-lengths and leads to formation of ozone by collisions.

Concerning the excitation of the singlet atoms we have no exact information but it may be caused by electron or ion impact, by chemiluminescence produced by the recombination of atoms. An estimate shows that the sun's radiation is intensive enough to produce so many oxygen atoms that an excitation by triple collisions has a sufficient probability. The green light of the night sky and the green afterglow of the aurora can be explained by this hypothesis. But also slow electrons with a kinetic energy of few volts may be responsible for the excitation of the green line in all such cases where the green line appears alone or as the predominant line.

Experiments to verify this hypothesis are in progress, the results of which will be published in subsequent papers.

Recently in this laboratory Kaplan could observe in the afterglow of a mixture of active nitrogen with oxygen the green oxygen line 5577.35 Å. and a red line 6654.8 Å. without other oxygen lines. Under these conditions the α-bands of nitrogen appear strong. Therefore it seems probable to me that the energy of two recombining nitrogen atoms can dissociate the oxygen molecule and excite the two atoms to the upper level of the green line in one act by a collision of the second kind. Perhaps the green oxygen line may be excited in the mixture of argon and oxygen in a similar process by a collision of the second kind with metastable argon atoms. Then the energy difference $^1D - {}^3P$ could not be greater than about 0.12 volt. Otherwise we have to assume that the convergence limit at 1750 Å. does not correspond to a dissociation into triplet atoms as Birge and Sponer believe. Probably then the molecule will be dissociated photochemically into two singlet atoms or one singlet and one triplet atom. The heat of dissociation of molecular oxygen would be in this case less than 7.02 volts. On the hypothesis of formation of singlet atoms by the solar radiation as described above, nothing would be changed, except that the second band spectrum should not be expected, as preliminary experiments seem to prove. The red line corresponds perhaps to a transition from the upper level of the green line to a lower ^1S term and should be visible in the spectrum of the aurora and the night sky, whenever the green line can be observed.

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CONCEPTS IN QUANTUM THEORY.*

BY

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General Considerations.—When a science makes rapid changes as has the science of physics during the last quarter of a century, there is perhaps an excuse for an occasional pause while we contemplate the structure before us and seek to ascertain which of its parts play vital rôles—where lies the heart which pumps through the organism the blood by which it works—how many of the pipes of the organ which play us the tune of physics are mere show pipes, and how many of them may not be removed without a loss to the essential harmonies of the composition.

An adequate attempt to clarify the situation in half an hour is impossible. Much that I shall have to say, therefore, must take the form of dogmatic assertion, and I must trust to the discussion to call forth further elaboration of those assertions which may seem most open to criticism.

First, then, we have the old electromagnetic theory itself. For while this theory has been demoted from the rôle of chief controller of the actions of the universe, it does become involved, even in the most recent of theories—that of Schrödinger—as part of the story.

$$\frac{\rho v}{c} = -\frac{1}{c}\frac{\partial E}{\partial t} + \text{curl } H, \tag{1}$$

$$\rho = \text{div } E, \tag{2}$$

$$0 = \frac{1}{c}\frac{\partial H}{\partial t} + \text{curl } E, \tag{3}$$

$$0 = \text{div } H. \tag{4}$$

* Presented at the Conference at the Loomis Laboratories in honor of Professor J. Franck, January 6, 1928.

Equations (1) to (4) are the so-called electromagnetic field equations. The origin of these equations is beset with hypothesis and mechanical concepts which could not stand for a moment as part of a complete logical structure of which modern atomic theory forms a part. But we do not need to question their ancestry in order to understand what they themselves have to say.

I think the only logical attitude towards these four equations is to regard them as definitions of the quantities E and H which they contain, in terms of ρ and ρv which are supposed assigned at each point in space. It is always in this sense that we use them. It is true that the coarse-grained phenomena of engineering practice permit definitions of E and H in terms of the forces on charges and on magnetic poles, but in application to atomic processes the starting point is always the assignment of ρ and v, and the assignment is followed by the *calculation* of E and H from these equations. All that the equations require of a density ρ and the velocity v in order that they shall form consistent definitions of E and H in terms of them is that ρ and v shall satisfy the equation of continuity,

$$\frac{\partial \rho}{\partial t} + \text{div } \rho v = 0.$$

Directly we have a ρ and a v satisfying these relations, we are ready to define quantities E and H by means of the electromagnetic equations. But you may well ask what we gain by merely defining quantities. We cannot discover laws of physics by definition. Where then does nature come in? She comes in in granting us that the quantities we have defined shall be of some use. And of use in what sense? Well, in old classical electromagnetic theory the belief was that the equation of motion of an electron could be expressed in terms of the values of E and H contributed by the charges other than that electron. In modern quantum theories, it is to the values of E and H emanating from, and representing, the light emitted from one atom that we still look for the

determination of events in other atoms, but in a manner different from that of the old classical theory. In certain forms of quantum theories the E and H determine probabilities of transitions. In others, they determine, in conjunction with some atom which they may encounter, a form of Hamiltonian function suitable for the subsequent discussion of events in that atom in terms of the modern theory.

But why do we choose quantities E and H defined in this way for the purpose of discussing the phenomena? We do so because these E and H's possess *properties by virtue of their definition*. Definition cannot discover laws of nature, but it can insure for the quantities defined certain properties. That is, quite regardless of any physical significance which E and H might have, or regardless of their having any power to do anything at all, their definition through the electromagnetic equations insures for them all those characteristics and potentialities which made them of service in the electromagnetic theory of wave motion. It guarantees such properties that their space and time variations go on according to the characteristics of wave motion—such properties as insure that, in a plane wave, the vectors lie in the wave front—such properties as insure the existence of a function of E and H, a vector (the Poynting flux of electromagnetic theory) which, at any rate in regions where the value of ρ is zero, has its surface integral taken over the boundary of the region equal to the volume integral of the time rate of change of $\frac{1}{2}(E^2 + H^2)$ taken throughout that region. The quantities E and H defined by (1) to (4) provide us with a language and with words suitable for the expression of the phenomena of physics.

Now if, in addition to the properties which E and H receive from their definitions via the electromagnetic equations, we endow them with the capability of moving electric charges in the manner demanded by classical theory, we evolve, as a consequence, details about optics, photoelectric effects, etc., which are out of harmony with the facts. If, however, we stop short at this point and confine ourselves to

more limited statements, we may stay within the realm of truth and yet gain some of the advantages inherent in the properties of E and H arising from their definition. Thus, for example, if we say that where E is zero nothing will happen we shall be consistent with the facts.

The older atomic theories sought to construct some relatively simple mechanism whose vibrations would correspond to the spectra of the atoms. The mere assignment of a number of simple harmonic oscillators, one for each frequency, would have served the purpose, but one revolts against such an explanation; and, if we should inquire why he revolts against it, I think we should be driven to say that for a theory to be satisfactory to him, it must deduce many things from few. In particular, the mind likes the idea of commencing with a thing which is simple as viewed from one standpoint and then showing that it has a complexity of properties from some other aspects, in the hope that this complexity of properties may reflect some set of properties found in nature. A square plate is a very simple thing from one standpoint. If we tap it, however, the vibrations are very complex, yet we should be perfectly happy if we should find that a square plate, or one of some other simple geometrical form, would give mechanical vibrations which were of the same frequency as those of some atom. We should very soon make a theory out of the situation.*

The essence of Bohr's theory lies in its starting with a fairly simple expression (the Hamiltonian function for the hydrogen atom for example), an expression with very few constants, and then setting up a mathematical procedure for getting a complexity of numbers out of that expression, these numbers representing the frequencies emitted by the hydrogen atom. The procedure, as we all know, is first to establish a subsidiary set of numbers, the so-called energy levels, and then specify the frequencies as their differences. Perhaps, of all theories, the Bohr theory presents the least

* Attempts in this direction have actually been made by Ritz ("Gesammelte Werke," Gauthier Villars, Paris, 1911).

attempt at a picture of the emission process itself. The vital thing is that it succeeds in starting with a simple mathematical expression for the atom and evolving by certain relatively simple mathematical operations a sequence of numbers whose differences are the frequencies. You will notice that I speak of starting with a simple mathematical *expression* for the atom rather than simple structure. The picture of an electron going around a nucleus, etc., is really superfluous as an interpretation to the mathematical procedure. The last vestige of claims of the picture to a fundamental importance in the matter disappears when it is realized that the action of the mechanism is not traced to the point of making evident the thing which, of all things, a mechanism should be designed to exhibit, the actual act of emission of the radiation.

Nevertheless, the model aspect of the Bohr atom did play a sort of dog in the manger rôle in not desiring to speak in detail about the vibrations themselves, at least to the extent of discussing their amplitudes, and yet using up all the dynamics available from the Hamiltonian equations for the purposes of the pure model picture. The Bohr theory thus makes a sort of transition in theories between the purely mechanical and the theories which merely content themselves with a formal statement of how things happen as distinct from why they happen.

The Matrix Theory.—In the matrix theory, we take the complete jump from mechanism to pure formalism, and we seek to write down a process for deducing from a certain construction of letters and numbers a two-fold set of quantities, one called amplitudes, and the other frequencies, which may form suitable material in terms of which to represent the optical behavior of the atom. All suspicion of a mechanistic significance of the ordinary kind, as attached to the procedure, evaporates when we note that the mathematical operations involved are of a class which do not obey the fundamental laws of algebra. It is a curious thing that the Hamiltonian function, which in the case of the hydrogen atom is, for example:

$$H = \frac{1}{2m}(p_x^2 + p_y^2 + p_z^2) - \frac{e^2}{r},$$

is of the same form as that used in the old dynamics, where it had an entirely different significance. This is merely an outcome of the fact that, in the Bohr theory, for example, as we have stated, it is not so much the picture of a model of the atom which gives us the results secured, as the form of the mathematical operations carried out on a Hamiltonian function of a certain type. In the matrix theory, enough of the properties of the original mathematical operations survive to enable this system of letters to serve again as a satisfactory starting point for the results derived.

As regards H itself, in relation to any picture of electron orbits in the sense of former theories, its meaning has completely evaporated. From the standpoint of the matrix theory, if you should ask me what a hydrogen atom is, I should have to reply, "It is the entity whose H suitable for the matrix operation is $H = (1/2m)(p_x^2 + p_y^2 + p_z^2) - (e^2/r)$." In the community of atoms, the hydrogen atom would be more appropriately known as Mr. $(1/2m)(p_x^2 + p_y^2 + p_z^2) - (e^2/r)$ than he would be known as Mr. Hydrogen.

Up to the point of obtaining the magnitudes which are to serve as amplitudes and frequencies, there is nothing to tie us down to any particular meaning to be attached to them. However, using no other criterion concerning them than the fact that they represent time variations of some quantity attached to a point in space—the point where the atom is—we can define in terms of them a set of vectors like the electromagnetic vectors in the same way as we can define by the electromagnetic equation a field E, H, for a vibrating doublet. The sinusoidal wave characteristics of E and H then follow from their definitions as already pointed out, and the crux of our assumptions is reached in the belief that the quantities E and H so defined can be used as suitable material in terms of which to predict the optical effects obtained when light falls upon a substance. On this view all of the frequencies

for the atom are operative at once. There is no talk of transitions between energy levels. It is quite true that the matrix theory does lead to a set of constants for the atom, equal in magnitude (with minor reservations) to the energy levels of the atom on the Bohr theory, but there is nothing to require that only one of these numbers is to be associated with the atom at any one time, and that the atom itself is to be regarded as suffering transitions from one energy level to another. If, however, with the idea of retaining the Bohr picture for reasons other than the optical, reasons associated with quantum phenomena, with collisions for example, we are willing to take one more step in the direction of pure formalism, we may regard the amplitudes calculated on the matrix theory not as amplitudes of an oscillating doublet at all, but simply in the following light. We may say that the atom can exist in only one state at a time. If it is in one of these states characterized by the constant W_1 (energy level on the Bohr theory), the probability that it will go to a lower energy level W_2 in a time $d\tau$ is proportional to the square of the amplitude q_{12} of the oscillation which the matrix theory gives as associated with the frequency $(W_1 - W_2)/h$. Then, in order to realize a definite intensity to the radiation emitted, it is necessary to add an additional postulate, quite unknown to the matrix theory itself, to the effect that the total energy radiated in the frequency ν_{12} is $h\nu_{12}$.

In spite of the purely formal nature of this specification of the interpretation of the amplitudes it is, in a sense, more satisfactory than one which attempts to regard these amplitudes directly as the amplitudes of an oscillating doublet; for it leaves open the magnitudes of the intensity to the extent of our assigning how many of the atoms are in the various energy states, and so it permits various distributions of intensities among the lines appropriate to various kinds of excitations. An attempt to picture the matrix amplitudes as the amplitude of an electric doublet would lead to two difficulties. In the first place the spectrum of the atom would be a definite thing independent of the degree of ex-

citation. In fact the theory would know nothing about excitation; and, in the second place, not only would there be nothing to symbolize the emission of radiation in quanta, but the radiation would go on forever. We cannot escape the latter objection on the ground that that which is radiated may not be energy, for the practical fact would be that one atom A would be able to produce continuous changes in its surroundings without itself suffering change; and, the denial of this possibility forms a postulate of nature more fundamental, if anything, than that of the conservation of energy.

Of course, in the form in which the matrix theory speaks of transition probabilities, and in the light of the picture of a number of stationary states, only one of which is possible at a time, what the matrix theory secures over the Bohr theory is that, except for questions of the uniqueness of the algebraic equations, a matter into which I will not enter, (1) it always is sure of leading to a definite and discreet set of energy states, which the Bohr theory is not; and (2) it leads to a definite set of amplitudes which may be used as material for the discussion of intensities. To the extent that the latter end is secured in the Bohr theory through the correspondence principle, it is only secured through the aid of an admixture of a certain amount of empiricism.

The Schrödinger Theory. Turning now to the Schrödinger theory, as exemplified in the hydrogen atom at any rate, we recall that, again, the starting point is a certain Hamiltonian form

$$H = \frac{1}{2m}(p_x^2 + p_y^2 + p_z^2) + V.$$

Replacing the p's by

$$p_x = \frac{\partial W}{\partial x}, \qquad p_y = \frac{\partial W}{\partial y}, \qquad p_z = \frac{\partial W}{\partial z},$$

where W is the action, it results that if we subject the p's and coördinates to the Hamiltonian equations,

$$\frac{1}{2m}\left[\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2\right] + V(x, y, z) + \frac{\partial W}{\partial t} = 0 \quad (5)$$

and for a conservative system, that is, one where V does not involve the time explicitly, $-(\partial W/\partial t)$ is equal to a constant E, the energy of the system.

While we think of W as applying to the particle, any solution of the above equations specifies a value of W for each value of x, y, z and t, independently of whether there be any particle at the point in question or not.

Consider any point on a surface over which, in some solution of this equation, W is a constant and then move perpendicular to this surface to another point at an infinitesimal distance dn. If we wait there for a time dt such that

$$0 = \frac{\partial W}{\partial t}\, dt + \text{grad } W \cdot dn, \tag{6}$$

we shall encounter the same value of W since we have chosen dn and dt in relation to each other in such a way that dW, which is represented by the right-hand side of (6), is zero. The value of dn/dt, which we shall write as u, represents the velocity with which we must move perpendicular to a surface of constant W in order that the value of W which accompanies us shall remain constant. We see from the above that

$$u = \frac{-\partial W}{\partial t} \Big/ \text{grad } W,$$

which, by noting that $\partial W/\partial t = -E$, and that, therefore, from (5), $[\text{grad } W]^2 = 2m(E - V)$, gives

$$u = \frac{E}{[2m(E - V)]^{1/2}}. \tag{7}$$

The quantity u is thus a definite function of position in space for the assigned problem with its given E and assigned V.

We now suppose that there is some quantity Ψ' which satisfies a wave equation

$$\nabla^2\Psi' - \frac{1}{u^2}\frac{\partial^2\Psi'}{\partial t^2} = 0, \tag{8}$$

with this velocity u occupying the position appropriate to the velocity.

We then limit ourselves to solutions of this wave equation of the form

$$\Psi' = \Psi(x, y, z)e^{(2\pi iEt/h)},$$

so that on substituting this in the wave equation itself we arrive at Schrödinger's equation

$$\nabla^2\Psi + \frac{8\pi^2 m}{h^2}(E - V)\Psi = 0.$$

As will be recalled, we then proceed to confine ourselves to cases where the differential equation has solutions for Ψ which are finite, continuous and single valued throughout all space. Taking the case where V has the form $-e^2/r$, this procedure leads to a restricted set of possible E's, at any rate for E negative. These E's are associated with the energy levels of the hydrogen atom and they are the same value as those given by Bohr's theory.

We now write down the quantity

$$\Omega = \psi_1 e^{2\pi iE_1 t/h} + \psi_2 e^{2\pi iE_2 t/h} + \cdots, \tag{9}$$

where Ψ_1 is a solution of Schrödinger's equation for $E = E_1$, Ψ_2 is a solution of the equation for $E = E_2$, and so on. We then write down the conjugate of this expression, namely,

$$\bar{\Omega} = \Psi_1 e^{-2\pi iE_1 t/h} + \Psi_2 e^{-2\pi iE_2 t/h} + \cdots, \tag{10}$$

and form $\Omega\bar{\Omega}$, which is

$$\Omega\bar{\Omega} = \psi_1^2 + \psi_2^2 + \cdots + \psi_1\psi_2 \cos\frac{2\pi}{h}(E_1 - E_2)t + \cdots. \tag{11}$$

By this device of multiplying Ω by its conjugates we realize a real quantity $\Omega\bar{\Omega}$ whose frequencies are the differences of the frequencies for the quantity Ω, and it becomes an appropriate quantity to christen electric density.

The association of $\Omega\bar{\Omega}$ with an electric density in the case of a system of many degrees of freedom carries us far into the realms of abstract thought, and I must content myself for the time being by confining attention to cases of no

more than three dimensions such as that of the hydrogen atom. The fact that, as can easily be shown, the value of $\Omega\bar{\Omega}$ when integrated throughout space is always constant enables us to define for it at each point in space a velocity v which will result in obedience to the equation of continuity

$$\frac{\partial \rho}{\partial t} + \text{div } \rho v = 0.$$

The quantities ρ and ρv thus defined may now serve to define a set of electromagnetic vectors through the circuital relations of electromagnetic theory, in the manner we have already indicated. The actual method of procedure adopted by Schrödinger is to define $\int\int\int \Omega\bar{\Omega} z d\tau$ for example as the z component of the moment of a doublet, the integral being taken formally throughout all space, but, in practice, effectively through only a very small part of it. The moment thus becomes the sum of a number of periodic terms of the form

$$M = A_{12} \cos \frac{2\pi}{h}(E_1 - E_2)t + A_{13} \cos \frac{2\pi}{h}(E_1 - E_3)t + \cdots A_{mn} \cos \frac{2\pi}{h}(E_m - E_n)t \cdots.$$

Now on this sketch of the theory a few remarks must be made. Considering the application of the foregoing procedure to the hydrogen atom, one's first reaction is one of concern on recalling that while the Hamiltonian function H is that for a particle revolving about a center of force, we have, by a rather tricky procedure, evolved another sort of a charge distribution. What is the relation between the two? Two courses are open to us in the adjustment of our mental equilibrium in this matter. We may deny that the original point particle had any status in reality at all, and we must then regard H as simply a mathematical form appropriate as a starting point from which to evolve by simple mathematical operations the set of numbers E_1, E_2, $\cdots$, etc., and also to evolve ultimately a definition of electric charge density and

so of electromagnetic vectors which can experience space time variations with the frequencies determined by the difference of the numbers E_1, E_2, $\cdots$, etc. The older theories started with the model, guaranteeing as far as possible simplicity for that from the start, and tolerating all subsequent complexity of mathematical expressions because they came from that nice model. Here our starting point to which we shall attach the label of simplicity is a mathematical expression. The model, the distribution of ρ, is devised from it and is a thing of complexity. Anyone who could have guessed the model at the start could, by working backwards, have arrived by processes of definition at our subtle expression for H and have shown, as we have shown, that an analytical equivalent of his guess was the formally simple starting point we have made. Let us be honest with ourselves, however. We should have objected to our friend's guess because he would have had to guess such a lot—so many E's, etc.

For anyone who wishes to retain the elementary picture of an electron and nucleus appropriate to the Hamiltonian function on the older lines of thought, a way is still open. We may regard the process we have outlined as that of setting up a method of specifying, or, if we like, a method of defining, through (8), a quantity ψ'—a wave motion which is associated with the particle—not associated in the sense that the particle produces the wave motion but merely in the sense that when one exists the other exists. And, in the same sense we may regard the distribution ρ which we specified as one associated with the charge without thereby being the same thing. If we like we may say that just as at the beginning of this paper we emphasized the definitional nature of the electric and magnetic vectors in terms of a density ρ and a velocity v supposed assigned, the justification for their being defined being a hope for their ultimate usefulness, so now we emphasize the definitional nature of ρ and ρv themselves in terms of another more fundamental entity, the electron of old classical theory, robbed now of all of its electromagnetic properties which are handed on to ρ and ρv, and retaining only its dynamical characteristics.

The Bohr theory merely carries matters to the stage of a determination of the energy levels and then says no more about the velocities other than that, somehow or other, they arise with frequencies equal to the differences of the energies divided by h. The Schrödinger theory goes further in defining a real quantity $\Omega\bar{\Omega}$ which can be associated with the ultimate charge density, and which then gives rise to electromagnetic vectors with wave characteristics and with the frequencies desired.

One of the criteria which presents the greatest artificiality at first sight is that which imposes the condition that the mysterious quantity ψ shall not be infinite at infinity. Little comfort can justifiably be derived from the general statement that no physical quantity can become infinite, for ψ has not made its appearance in the analysis heralded by any particularly physical sponsors. It would seem to have no more right to that mysterious title involved in the term physical quantity than $1/\psi$ has. We should be perfectly happy to have ψ zero at infinity, as indeed it turns out to be, and in this case $1/\psi$ would be infinite there, a curious truth which ought to alarm anyone who pins his faith on the finiteness of everything which he calls a physical quantity. I think, however, it is possible to impart a satisfactory amount of meaning into the condition that ψ shall not be infinite at infinity by observing that insofar as the amplitudes of the harmonic terms which constitute ρ turn out to be of the form $\psi_m\psi_n$, values of ψ which were infinite at infinity would, in general, lead to charge densities which were infinite there. Our restriction to cases where the ψ's are not infinite at infinity amounts, therefore, not so much to a vital restriction, as to a *limitation of our interest* to those problems for which the charge density is not infinite at infinity. Put in other words, we may say that it is our intention to try and get on, as far as the correlation of all natural phenomena is concerned, by restricting our atomic pictures to those in which ρ is not infinite at infinity.

There is another matter concerned with the quantity ψ'

which is worthy of comment. ψ' is the quantity which satisfies the wave equation (8) and with which is associated the velocity u. It is the so-called waves of this quantity which are regarded as diffracted by a grating in such a manner as to correspond to the experiments of Davisson and Germer on the diffraction of electrons by crystals. Let us recall the argument.

The energy associated with the electron is purely kinetic, so that $E = \frac{1}{2}mv^2$. The ψ' waves which are associated with the electron consequently have a velocity

$$u = \frac{E}{\sqrt{2m(E - V)}} = \left(\frac{E}{2m}\right)^{1/2}.$$

The frequencies of these waves is E/h so that the wavelength is:

$$\lambda = \frac{u}{\nu} = \frac{hE^{1/2}}{\sqrt{2mE}} = \frac{h}{mv}.$$

Experiment shows that the electrons are treated by the crystal as electromagnetic waves having this wavelength would be treated. But the ψ' waves are not electromagnetic waves. As a matter of fact ψ' is not even a real quantity for $\psi' = \psi e^{2\pi i E t/h}$. Ordinarily when we write a quantity with an imaginary exponent we desire it to be understood as meaning thereby only the real part. Such is not the case here, however, for it is precisely because ψ' is the whole complex quantity $\psi e^{2\pi i E t/h}$ that the expression when multiplied by its conjugate gives rise to a real charge density with frequencies determined by the differences of the E's. We thus have the spectacle of a really "complex" quantity acting on a real crystal in such a way as to suffer diffraction by means of it. Now, I do not think that we ought to shut our eyes to the possibility of using complex quantities in our physical theories in such a manner as to give them a more dignified status than that of mere analytical intermediaries. We might enrich the content of our means of expressing valuable relationships by attaching to a planet three complex quantities

for its coördinates instead of three real numbers. It might be that equality of the real parts for two planets might symbolize a collision and equality of the imaginary parts, some other common property. However, we do not customarily do this kind of thing, so that it is just as well to realize quite clearly that we are doing it when we speak of the ψ' waves as being diffracted by a crystal. I hope to show presently how we may avoid the undesirable features associated with a "complex" ψ' function, but, before doing this, I should like to raise another difficulty in order that we may make an attempt to overcome both difficulties at the same time.

Returning once again to the ultimate picture presented by the Schrödinger atom for the three-dimensional case, the quantities ψ in the expression for the density are undetermined to the extent of arbitrary constant factors, so that without further specification there is nothing to fix definitely the relative amplitudes of the harmonic terms in the expression for the electric moment associated with the atom. The missing feature becomes filled in by what turns out to be a possible association of the coefficients of the harmonic terms in question with the elements q_{mn} as given by the matrix theory. I do not propose to discuss this matter further than to remark that even when the coefficients have become fixed we are in the same difficulty as we were in with the matrix theory in respect to the meaning of the results obtained. The immediate interpretation implies all the frequencies as coexistent at once, and fails to provide for radiation in quanta. We can still revert to the formal plan of saying that the picture does not represent the facts at all, and that we really do have stationary states represented by the E's, that the atoms can only be in one of their states at a time, and that the coefficients referred to above determine the probabilities of transitions. Unfortunately, our definition of charge density and our realization of a vibrating mechanism in terms of this charge density are carried too far in the theory to permit us to rob the charge so defined of the power to complete the

whole story—at least if we do rob it of this power there remains nothing to our feat of having brought it into existence, and the whole theory reverts to a purely formal procedure for calculating the frequencies and intensities.

In spite of the above difficulty, a way is open to us of preserving a significance to our charge density—at least in a case of no more than three degrees of freedom; and, at the same time, we shall be able to avoid the unwelcome concept of a ψ wave which is complex.

Our starting point is again the equation

$$\frac{\partial^2 \psi'}{\partial t^2} = u^2 \nabla^2 \psi', \tag{12}$$

but instead of writing $\psi' = \psi e^{2\pi i E t/h}$ we shall write

$$\psi' = \psi \cos 2\pi E t/h \qquad \text{or} \qquad \psi \sin 2\pi E t/h.$$

Each of these, when substituted in (12), leads to Schrödinger's equation for ψ, so that they serve as well as the solution $\psi' = \psi e^{2\pi i E t/h}$ for the purpose of leading to a means of specifying characteristic values of E through that equation.

Now, however, instead of defining Ω by the sum of a number of terms involving all the possible values of E as in (9), we reconcile ourselves to the belief, so familiar in the old Bohr theory, that even when radiation is occurring, the atom may be in one state of radiation or in another, but it can only be in one state of radiation at a time, and that in the expression of this state only the two energy levels associated with the particular transition are involved. For the state of radiation typified by the subscripts m, n, we make the following definitions:

$$S_m \equiv \log [\psi_m \cos 2\pi E_m t/h],$$
$$S_n \equiv \log [\psi_n \cos 2\pi E_n t/h],$$
$$\bar{S}_m \equiv \log [\psi_m \sin 2\pi E_m t/h],$$
$$\bar{S}_n \equiv \log [\psi_n \sin 2\pi E_n t/h].$$

We then define

$$S \equiv S_m + S_n = \log \psi_m\psi_n \cos\frac{2\pi E_m t}{h} \cos\frac{2\pi E_n t}{h},$$

$$\bar{S} \equiv \bar{S}_m + \bar{S}_n = \log \psi_m\psi_n \sin\frac{2\pi E_m t}{h} \sin\frac{2\pi E_n t}{h},$$

and finally we define ρ as

$$\rho \equiv eS + e\bar{S} = \psi_m\psi_n \left[\cos\frac{2\pi E_m t}{h} \cos\frac{2\pi E_n t}{h} + \sin\frac{2\pi E_m t}{h} \sin\frac{2\pi E_n t}{h} \right],$$

$$\rho = \psi_m\psi_n \cos\frac{2\pi}{h}(E_m - E_n)t. \qquad (13)$$

so that again we have realized a definition of ρ having the desired characteristics, but without importing, as an intermediary, a ψ' wave having to do with other than a real quantity. One might be inclined to criticize the above procedure on the basis of artificiality, but it is really no more artificial than its immediate predecessor, for in that there was no reason for defining ρ as it was defined by (11) other than the fact that the ρ so defined had the appropriate frequencies. Indeed the ρ which we have defined in (13) has a more clearly understandable status than has the old ρ. We may, if we like, regard it as the ρ belonging to the virtual oscillator of Bohr, Kramers and Slater [1] for the frequency ν_{mn}. It is, I think, better to regard it as having no particularly close relation to the electron's charge. It is something which comes into existence during the "transition." One with ultra-materialistic leanings will probably wish to regard it as precipitated from the æther, to be redissolved again when its task is accomplished. Even if its creation violates the equation of continuity, the conservation of its total amount provided for by the normal functional nature of ψ_m and ψ_n enables us to define, as associated with it at each point of space, a velocity v which preserves the equation of continuity during its existence in the form specified by (13);

[1] *Phil. Mag.*, S. 6, Vol. 47, pp. 785–802, 1924.

and, with this properly assured, it can serve in conjunction with ρv to define a set of electromagnetic vectors E, H, satisfying Maxwell's equations, as already explained.

For a one-dimensional case, corresponding to a free particle moving with velocity ω, the procedure above sketched leads to the two solutions

$$\psi' = \psi \cos\frac{2\pi Et}{h} \qquad \text{and} \qquad \psi \sin\frac{2\pi Et}{h},$$

with ψ satisfying Schrödinger's equation, which in this case takes the form

$$\frac{\partial^2\psi}{\partial x^2} + \frac{8\pi^2 m}{h^2} E\psi = 0,$$

leading to the two solutions

$$\psi = A \cos\frac{\pi}{h}(8mE)^{1/2}x \qquad \text{and} \qquad B \sin\frac{\pi}{h}(8mE)^{1/2}x.$$

ψ' then has the various possible values

$$A \cos\frac{\pi}{h}(8mE)^{1/2}x \cos\frac{2\pi E}{h}t, \quad B \sin\frac{\pi}{h}(8mE)^{1/2}x \sin\frac{2\pi E}{h}t,$$

$$A \cos\frac{\pi}{h}(8mE)^{1/2}x \sin\frac{2\pi E}{h}t \quad \text{and} \quad B \sin\frac{\pi}{h}(8mE)^{1/2}x \cos\frac{2\pi E}{h}t.$$

By combining two such solutions we can, of course, construct a quantity proportional to

$$\cos\left[\frac{2\pi E}{h}t - \frac{\pi}{h}(8mE)^{1/2}x - \delta\right]$$

representing a wave traveling with velocity $2(E/8m)^{1/2}$. Putting $E = \frac{1}{2}m\omega^2$, the velocity of the wave is $\omega/2$.

If one attempts a procedure similar to the above in the case of a system of more than three degrees of freedom, he encounters a difficulty arising from the fact that ρ then becomes defined in the space of the generalized coördinates, and there is no immediately obvious way in which a physical significance may be preserved for it. However, a little further scrutiny of the matter raises the question as to

whether there was ever any necessity to have brought it into existence at all.

Two quantities ρ and ρv are necessary, in general, to serve as a starting point for the definitions of a pair of vectors E and H satisfying Maxwell's equations. By proceeding to the limiting case for two equal and opposite charges in close proximity, we may, however, realize definitions of E and H requiring only the specification at each point of a vector M and its time derivative, $\dot{M}$ corresponding of course to the moment of a doublet. In particular, the specification of M and $\dot{M}$ at *one particular point* is sufficient to serve as the starting point for the definition throughout all space of a pair of vectors E and H satisfying Maxwell's equations.

Now, except for slight complications in the algebraical expressions, the argument we have already made down to equation (13) applies as well for a multidimensional as for the three-dimensional case, but in the former case ψ_m and ψ_n are functions of all the generalized coördinates, so that ρ no longer has a significance as attached to a three-dimensional space. The subsequent procedure usually adopted for arriving at the moment by integrating throughout the multidimensional space does, however, lead to a definite quantity M, a vector characteristic of the atom and of the m-n transition, a vector, moreover, whose magnitude varies harmonically with the frequency ν_{mn} desired. The analysis does not assign any point of application for this vector. On the other hand, it does not place any restriction on our assigning it to a single point in the atom, if we so wish. If it had represented this vector as a sort of resultant of a number of vectors applied at different points of the x, y, z space, we would not have been at liberty to regard it other than in the light in which the analysis presented it to us. As matters stand, however, we are free to assign this vector to any point of the atom we choose, and it with its time rate of change provides a basis for defining our E and H throughout space, without any further thought of a real density distribution ρ associated with it.

It is perhaps worth while to bear in mind that a grave difficulty always remains in any theory which seeks to attain its end by providing for an oscillator which sends out waves of some kind or other as the causes responsible for the optical effects. The difficulty is concerned with the comparative rarity of such phenomena as the photoelectric effect—the old question as to why all parts of the wave front do not produce the same effect. The difficulty of an ordinary electromagnetic wave being unable to give to an electron in a reasonable time photoelectric energy comparable with that observed is not one which need trouble us seriously, for an adjustment of the law of force might readily be made to overcome this. Such adjustment does not provide for the fact that only an electron here and there is ejected, however. We have always revolted against the thought of only a few atoms being in a state receptive to photoelectric influence, and if we decide to rule this thought out of court, and yet retain the electromagnetic wave idea as a language in which to describe the phenomena, it must be in the capacity of a guide to determine the paths of quanta, for example, through the agency of the so-called Poynting vector, or as a controller of the probability of quantum events that we must regard the vectors. Formally, the Schrödinger theory has its own method of determining such a phenomenon as a photoelectric effect; at least such is the case in a view which regards the electrons as synonymous with the distribution of ρ with which the theory concerns itself. For, the logical pursuit of the consequences of the theory makes us see the light wave coöperating with the atom whose electron is to be ejected in such a way as to secure for the system of atom and light wave a Hamiltonian function which shall in turn lead to a Schrödinger equation which will, in the ultimate solution for ρ as a function of x, y, z, tell the story of the photoelectron's departure from the atom. Even here, however, there seems to be nothing obviously available to provide for the infrequency of the event.

ANOMALOUS KERR EFFECT IN SODIUM VAPOR.

BY

ARTHUR BRAMLEY, Ph.D.

Bartol Research Fellow.

BARTOL RESEARCH FOUNDATION
Communication No. 22.

THE discovery was made by Kerr that a transparent isotropic medium became doubly refracting when placed in a powerful electric field, the rotation of the plane of polarization being proportional to the square of the electric intensity E. If, therefore, we let n_p and n_s be the refractive indices for light vibrating parallel and perpendicular respectively, to the direction of the applied electric intensity, then the specific rotation, i.e., Kerr's constant K is given by the relation that

$$K = \frac{n_p - n_s}{\lambda E^2}, \qquad (1)$$

where λ is the wave-length of the polarized light for which the double refraction is measured, the direction of propagation of the incident beam of polarized light being perpendicular to the direction of the applied electric field.

The natural explanation of this effect is to regard the plane polarized light as separated into two circular components with opposite rotation, then the rotation of the plane of polarization will depend on the difference in the refractive indices for the components of each of these components. On the basis of this simplification, together with the results of the classical theory of dispersion, a value for the specific rotation in terms of known constants has been derived by Gans [1] and others, which agrees well with the experimental results for the case of an applied electrostatic field.

On the basis of this theory, it can be shown that the specific rotation can be expressed in the following form

[1] *Ann. der Physik*, Vol. 65, p. 97 (1921).

$$K = \frac{3\pi\nu}{\lambda}\theta,$$

where ν is the number of molecules or atoms per unit volume and

$$\theta_1 = \frac{1}{48kT}[(A - B)(A^1 - B^1) + (B - C)(B^1 - C^1) + (C - A)(C^1 - A^1)], \quad (2)$$

where k is Boltzmann's constant per molecule; T is the absolute temperature; A, B and C the moments induced in the molecule along three perpendicular axes by unit electric force in the incident light wave acting along these three directions; and A^1, B^1, and C^1 the similar moments induced along the same directions by unit electric field E which produces the double refraction.

For a non-polar molecule in the presence of an electrostatic field E,

$$\frac{A^1}{A} = \frac{B^1}{B} = \frac{C^1}{C} = \frac{\delta - 1}{n^2 - 1},$$

where δ is the dielectric constant and n the refractive index outside the field.

The expression for θ, then becomes

$$\theta_1 = \frac{1}{45kT}\frac{\delta - 1}{n^2 - 1}[(A - B)^2 + (B - C)^2 + (C - A)^2].$$

Now from the theory of light scattered by an optically anisotropic molecule, the factor of depolarization, r, of the transversely scattered light is given by

$$r = \frac{6[(A - B)^2 + (B - C)^2 + (C - A)^2]}{10\left[\frac{2(n - 1)}{2}\right]^2 + 7[(A - B)^2 + (B - C)^2 + (C - A)^2]}$$

where the factor of depolarization is defined as the ratio of the difference of the intensities of the scattered light polarized in two mutually perpendicular directions to the sum of those intensities, or

$$r = \frac{J_1 - J_2}{J_1 + J_2},$$

where J_1 represents the intensity of the scattered light polarized in one direction and J_2 that of the light polarized in a direction perpendicular to the first.

From these equations we readily obtain as the relation between Kerr's constant and the factor of depolarization

$$K = \frac{3(n-1)(\delta-1)}{4\pi\nu kT} \cdot \frac{r}{6-7r}. \qquad (3)$$

As an example of the type of agreement existing between theory and experimental observations, we shall consider the case of CO_2, for which

$$r = 9.8 \times 10^{-2},$$
$$n - 1 = 4.18 \times 10^{-4},$$
$$\delta - 1 = 8.93 \times 10^{-4},$$
$$K = 0.24 \times 10^{-10} \text{ observed.}$$

From the calculation of the above expression for k we find

$$K = 0.28 \times 10^{-10},$$

which is a very satisfactory agreement, considering the accuracy of the experimental observations is no more than 10 per cent.

H. Kopfermann and R. Ladenburg,[2] in their investigation of the double refraction of sodium vapor at 200° C., i.e., at a pressure of 10^{-5} mm. of Hg. approximately, found a value for the change in index of refraction of

$$n_p - n_s = 3.5 \times 10^{-7},$$

which resulted from the passage through a region 2.8 cm. long within the electric field, whose electric intensity was 100 e.s.u.

$$\text{so that } K = \frac{3.5 \times 10^{-7}}{5.9 \times 10^{-5} \times 10^{4}} = .59 \times 10^{-6}.$$

In order to account, then, for the experimentally determined results, Ladenburg and Kopfermann derived an expres-

[2] *Ann. der Physik*, Vol. 78, p. 659 (1925).

sion of the following forms from the considerations involved in the quantum theory discussion of the Stark effect.

$$K = k(n^2 - 1)(\lambda^\pi - \lambda^\sigma), \tag{4}$$

where k is a known constant.

n is the refractive index for the wave-length of the light whose rotation of plane of polarization is determined.

λ^π is the wave-length of the Stark component whose emitted radiation is polarized parallel to the electric field

and λ^σ is the wave-length of the Stark component whose light is polarized transversely to the field.

Since the Stark separations are proportional to the square of the electric intensity, the formula gives qualitative agreement with the experimental data.

From their measurements on the Kerr effect, Ladenburg and Kopfermann find for the Stark separation $\lambda^\pi - \lambda^\sigma$, at 30,000 volts per cm.,

$$\text{the value } \lambda^\pi - \lambda^\sigma = 0.75 \times 10^{-3} \text{ Å.},$$

while from the Stark effect separation in sodium vapor,

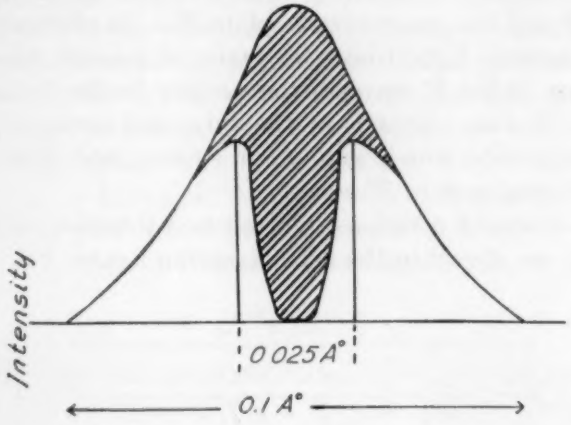
$$\text{the value } \lambda^\pi - \lambda^\sigma = 0.88 \times 10^{-3} \text{ Å.},$$

is found, which is very satisfactory agreement with the experimental data obtained from different sources, considering that they assumed that the probabilities of the two types of transfer were equal.

However, in order to compare the calculated value for the Kerr constant with the experimentally determined value of the same, account had to be taken of the structure of the sodium line after passing through several cm. of absorbing vapor. From an investigation of the structure of the line, Ladenburg found that the center of the line had been entirely absorbed so that the line could be regarded as two lines at a distance 0.025 Å. apart; the intensity distribution of the original and the absorbed line are shown in Fig. 1. Since, however, the rotation is the same on both sides of the central line, the specific rotation will be equal to that due to either

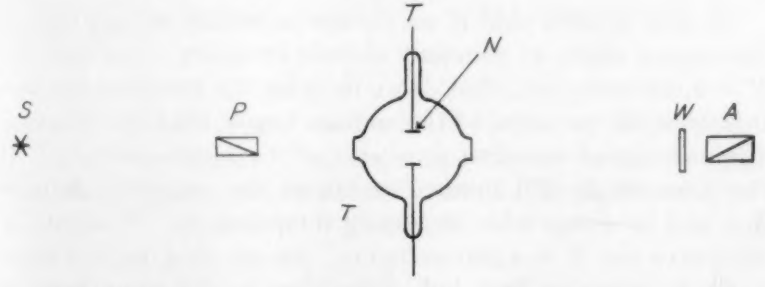
of the two components present after passing through the absorbing layer of vapor.

FIG. 1.



In the experiment we are going to describe, the Kerr constant was measured at the two voltages of 2,000 and 1,000 volts/cm. respectively for sodium vapor at the vapor pressure corresponding to its equilibrium with sodium for temperatures between 130° C. and 350° C. illuminated with the sodium *D* lines. The diagrammatic sketch of the apparatus is shown in Fig. 2.

FIG. 2.

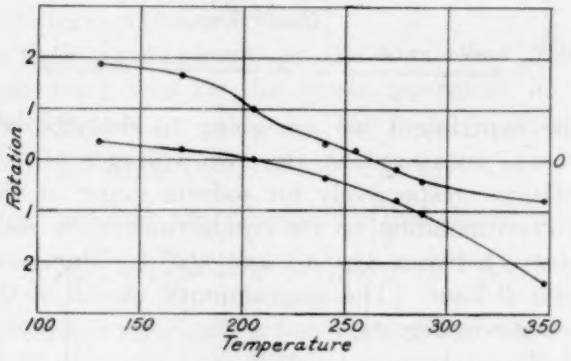


This consists of the source *S*, a sodium gas burner, the tube *T* which is inside of an electric furnace which allows the temperature of the tube to be varied within the described limits—this tube contained two nickel plates placed parallel

to its axis 3 cm. apart and supported by tungsten leads sealed through the glass wall. The rotation was observed by means of the polarimeter, consisting of the analyser A, the polarizing nichol P and the quarter wave plate W. In the operation of the apparatus, light from the source S passed through the polarizing nichol P, through the window in the furnace, into the cell T along the axis of the tube and between the two plate electrodes, which were 2 cm. square, and then through the analysing system W and A.

The observed rotations, plotted as a function of the temperature are shown in the accompanying figure.

FIG. 3.



It will be seen that if we fix our attention on any one of the curves taken at constant electric intensity, e.g., that for V = 2,000 volts/cm., that as we increase the temperature and therefore the pressure of the sodium vapor that the rotation diminishes and becomes zero at 220° C. approximately. If the pressure is still further increased the rotation changes sign and increases with increasing temperature. If we study the curve for V = 1,000 volts/cm., we see that the rotation is much larger at first but diminishes in the same way as that which we have just described, falling to zero at 275° C. approximately. After this point the rotation increases with increasing pressure in the reverse direction and exhibits the normal Kerr effect, i.e. the rotation is $\frac{1}{4}$ that of the curve for V = 2,000 volts/cm. at the same temperature, as we should

expect from equation (1) or (3) connecting the rotation with the square of the electric intensity.

The quantum theory of the Kerr effect which we have just considered is obviously unable to account for the phenomena observed at low temperatures, where the absorption is small, because it is not at the present time in a position to account for anomalous dispersion. However, besides the classical presentation which we considered first, Voigt [3] has calculated for a harmonic oscillator the rotation produced by an electric field when the oscillation is acted on by a restoring force F proportional to the displacement x of the form

$$F = (K + fX^2)x,$$

where k and f are constants associated with the oscillator and X the electric intensity in the x direction at the atom due to the externally applied electric field.

From this assumption, he finds the following values for the index of refraction n^π and n^σ for light whose electric vector is parallel and transverse to the direction of the applied field respectively,

$$n_\pi^2 = n_0^2 - \frac{\rho}{\bar{\nu}_0(\mu - \mu_0^\pi - i\bar{\nu})}, \qquad i = \sqrt{-1} \qquad (5)$$

and an analogous formula for n_σ, where ν_0 is the position of the line, when no field is applied, ν the frequency of the incident light.

$$\mu = \nu - \nu_0.$$

ρ and $\bar{\nu}$ are constants associated with the oscillator and n_0 is the index of refraction, neglecting the term due to the line at the frequency ν_0, while μ_π is the displacement of the line due to the internal field, where

$$\mu_\pi = cX^2$$

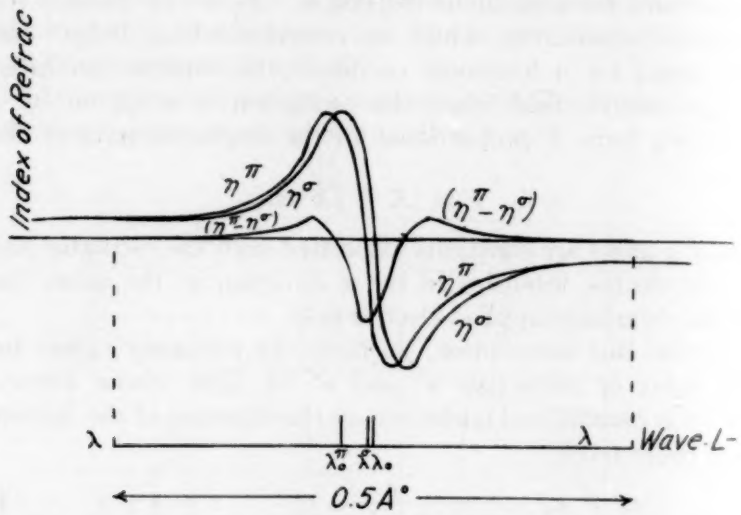
according to the theory of the Stark effect.

In Fig. 4 are shown the values of n_π, n_σ and $n_\pi - n_\sigma$ calculated according to this theory in the vicinity of the line at ν_0. The curve in Fig. 1 represents the distribution of light

[3] Voigt, "Magneto und Elektrooptik."

intensity in the incident beam whose rotation we are measuring. The effect of changing the electric field is to displace the curves n_π and n_σ by an amount, which, according to the theory of Voigt, is equal to the displacement of the Stark components, but without altering the form of the functions.

FIG. 4.



From Fig. 4, which represents the rotation at a field of 30,000 volts/cm., we see that at a low temperature, e.g. $T = 130°$ C., where the absorption is negligible, the average rotation of the incident beam is negative, whereas at $T = 220°$ C. where the central part of the incident beam has been totally absorbed (represented by the shaded area in Fig. 1), the average rotation is positive and varies directly as the square of the electric intensity, since the rotation outside of the maxima A and A' can be calculated according to the simpler theory given in equation (4). Such, in general character, is the type of phenomena observed in the two curves given for electric intensities of 1,000 volts/cm. and 2,000 volts/cm. respectively. However, since the position of the points where $n_\pi = n_\sigma$ are displaced only an inappreciable amount by altering the electric field, we would expect from this theory that the magnitudes of the temperatures for which the rotation

was zero would be unaltered by applying the electric field and also that at $T = 220°$ the rotation would be positive on account of the absorption band. We actually found, however, that the experimental values are zero or negative; however, the values found by Ladenburg and Kopfermann at 30,000 volts/cm. gradient give a large positive rotation as we would expect, from the manner in which the values of the specific rotation vary with electric field in the experiments described above (see Fig. 3).

In the considerations, so far, we have neglected the probability of the various transitions involved in the process we are considering. If we introduce the probability factors A^π and A^σ respectively for the probabilities of the transitions from the two new energy states of the Stark pattern, then equation (5) takes the form

$$n_\pi^2 = n_0^2 - \frac{\rho A^\pi}{\nu - (\mu - \mu^\pi - i\nu)} \qquad (6)$$

and a similar equation for n_σ^2.

Now we know from the experiments on resonance radiation that the probability coefficients A^π and A^σ approach equality as the temperature or the electric field is increased. Thus we would expect the duration of rotation would depend at low temperatures in a marked manner on the probability factors as is predicted by theory.

Now for equal Stark and Zeemann separations the amounts of polarized resonance radiation at the same temperature should be equal,[4] so that the data on radiation scattering in magnetic fields ought to be able to give us some information on the probability coefficients in an electric field. The work of Datta [5] has shown that the resonance radiation increased markedly as the temperature was lowered and also that at low field strengths the percentage of the radiation polarized is much greater than we would expect and may even equal that for much greater fields at these temperatures, e.g. $T = 135°$ C.

[4] Hanle, *Zeit. f. Phys.*, Vol. 35, p. 346 (1926).
[5] *Zeit. f. Phys.*, Vol. 37, p. 625 (1926).

Solar Radiation in the Extreme North. O. KESTNER. (*Naturwissenschaften*, Nov. 4, 1927.) It is well known that in high northern latitudes many plants bloom and come to maturity in spite of the brevity of the summer. There is in addition much similarity between Arctic and Alpine fauna and flora. How is it that in the far north plants can accomplish so much in the brief time at their disposal? It is certainly not because of a higher average temperature. May in Hamburg is about 8.5° C. warmer than Hammerfest. The greater length of the day accounts for only a part of the difference.

Recently investigation has shown that not only temperature but also the ultraviolet content of the radiation from the sun plays a part in the development of animals and plants. Especially the shorter waves of this spectral range favor metabolism, increase the number of red blood corpuscles and aid in the formation of valuable chemical compounds in the organism. Measurements made on these rays with the cadmium cell led to the expectation that, owing to the low altitude attained by the sun in northern regions, there would be there a lack of the short waves. The author made observations in Lappland and other parts of the Scandinavian Peninsula and found that the intensity of ultraviolet light from the sun is greater in northern regions than in Hamburg. When the sun was 40° above the horizon in a northern station, the instrument gave an indication about twice as large as for the sun at the same altitude in Hamburg. The curve connecting altitude of the sun and instrument readings made in the north lies between like curves for Germany and for the Jungfrau in Switzerland. When not only the radiation coming directly from the sun to the instrument but also that reaching it after diffusion was taken into account, the difference in favor of the north in respect to Germany was much more marked. Ernst claims that plants as well as man depend upon the ratio of ultraviolet radiation to heat. The numerator of this fraction is large for high mountains and for northern latitudes. The denominator is small for the same two regions. From this similarity results the resemblance in the organic life in these two parts of the earth, and from the relatively large value of the ratio comes the explanation of the rapid growth of plants during the Arctic and the Alpine summers. G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

STEVENSON CREEK (CALIF.) ARCH DAM.

THE Bureau of Standards has coöperated with the Committee on Arch Dam Investigation of the Engineering Foundation in the construction and testing of a concrete arch dam in the mountains near Fresno, California. The electric telemeter developed by McCollum and Peters of the bureau was used in the tests and made possible the measurement of strains with a high degree of precision at places entirely inaccessible by other means. Ideas for other instruments partially developed at the bureau were furnished to the committee and, after further development, instruments based on these ideas were successfully applied in the work. W. A. Slater of the bureau's staff spent approximately two years in California in charge of the test and in the preparation of the report.

No further tests have been made since the note published in *Technical News Bulletin No. 117* (January, 1927). However, the dam has undergone severe tests occasioned by floods since the time that the former news item was prepared. A flood which destroyed all the observation platforms and caused the choking of the undersluice filled the reservoir with rock, sand, and silt to an average depth of about 40 feet at the upstream face of the dam. With this debris against the dam the water filled the reservoir and at times rose to a height of about 3 feet above the crest of the dam. From November, 1926, to July, 1927, and again during the present winter the reservoir has been full and a small amount of water has been running over the top of the dam. The only observed effects produced by this unexpected pressure of debris and water have been a slight extension of one of the cracks near the bottom of the dam, which occurred during a previous load test, the formation of an additional crack near the bottom,

* Communicated by the Director.

and a small increase in the deflection of the dam. At the time of the latest examination (July 13, 1927) all other cracks remained about as they appeared in October, 1926.

The test has yielded results which give direct information on the temperatures in the concrete, and on strains, stresses, and deflections in the dam. The results also afford a basis for comparison with the stresses and deflections as computed by current methods of design. There was reasonably good agreement with the computed stress at approximately the mid height of the dam, but at the top the agreement was poor. Results of tests on a celluloid model of the dam at Princeton University agree so well with the results from the actual structure that added confidence is felt in the use of models in designing arch dams. The Bureau of Reclamation is building a concrete model of the Stevenson Creek dam at the University of Colorado, Boulder, Colo., which will be tested for comparison with the Stevenson Creek dam, also a model of the Gibson dam, which is to be built in Montana and which will be about 900 feet long and 165 feet high. The model will be tested as a check on the design of the dam as made by the Bureau of Reclamation.

The highest temperature observed in the concrete was about 47° C. (117° F.). This occurred at an elevation of about 4 feet within about 24 hours after the placing of the concrete. The dam is about 6 feet thick at this elevation. The decrease from maximum temperature was rapid and an equilibrium with the air temperature was reached in about ten days.

At about 12 feet above its lowest point the dam cracked loose from the abutments within a few days after placing the concrete at that elevation. Before the beginning of the load tests the dam had cracked loose from the abutments on the upstream face most of the way from this elevation to the top of the dam. On the downstream face the cracking loose from the abutment extended from the top of the dam downward to about the 30-foot elevation. At the bottom of the dam under a head of water between 30 and 40 feet there was

a separation from the foundation at the upstream face. With a head of a little less than 50 feet a vertical crack occurred on the center line of the dam extending downward about 11 feet. This crack extended entirely through the thickness of the dam, but it was wider on the downstream than on the upstream face. The crack closed as the water was raised to the top of the dam. With later loadings the crack extended somewhat until, within a short time, it had extended downward about 20 feet. The loading due to the flood water and debris seemed to have no further effect on this crack.

With a head of 60 feet a vertical crack formed on the downstream face of the dam at the center line from about 2 inches above the bottom to a height of 9 feet. Later it extended to a height of 13 feet. The telemeter readings indicated that this crack did not extend through to the upstream face.

Leakage through the dam was small at all times. With heads less than 50 feet it showed up merely as moist spots at a few places not over 8 inches in diameter. With higher heads and long-continued pressure some of the construction joints opened slightly, permitting some increase in the leakage.

The highest stress indicated by the measured strains was a compression of about 1,100 lbs./in.^{2}. This stress was found at a single point. Everywhere else the stress was considerably lower. The compressive strength of the concrete at this age as indicated by tests of 6 by 12 inch cylinders 3 months old was about 2,800 lbs./in.^{2}.

The strains measured by different methods were in fair agreement with each other and from these strains it was possible to determine with reasonably good approximation the amount and distribution of the loads carried by arch action, and by bending in both the vertical and horizontal elements. The agreement of the sum of the loads so determined with the total water pressure forms a check on the approximate correctness of the results.

WORKABILITY OF CONCRETE.

A SUMMARY of the study of the methods for measuring the workability of concrete which has been conducted at the bureau was presented at the convention of the American Concrete Institute at Philadelphia, February 28–March 1.

The plastic properties of neat cement pastes were first studied, by measurements of the velocity of a ball pulled through the paste. This apparatus gave data of interest but could not be applied to the study of the workability of concrete. Next a study of the separation of the concrete on the flow table was made. After flowing, the concrete was divided into two equal areas by two concentric circular cutters. The volume and weight of aggregate coarser than the No. 4 sieve in each portion were measured, and the workability figure calculated as a function of these measurements. Several shapes of flow table and heights of drop were used. There was an indication that the best results were obtained with the flat-top table operated with a 1/16-inch drop. This method was not, however, found completely satisfactory since the influence of mixing time could not be determined. The next method which was used measured the internal resistance to shear of the concrete by the deformable cylinder, as described in *Technical News Bulletin No. 114*, October, 1926. The results obtained with this method were encouraging but did not show a marked difference in workability of lean concrete mixes. The final study was made with a modification of the Pearson and Hitchcock penetration rod apparatus. This apparatus was modified by making each drop of the weight a constant and then by increasing the number of rods from 1 to 3. This apparatus has given the most satisfactory index of workability thus far obtained.

The principal results obtained from the tests may be summarized as follows:

1. The workability as determined by the separation of the concrete on the flow table was not satisfactory for several reasons. The individual measurements varied too greatly, the measurements on mixes of different proportions did not

show markedly different results, and the personal element also entered too markedly into the tests.

2. The deforming cylinder apparatus did not measure the workability of lean mixes of different proportions distinctly and conclusively, nor was the test sensitive enough to measure the effect of increase in the mixing time upon the workability.

3. The modification of the penetration rod apparatus by driving in the rod by a falling weight instead of by the inertia of the rod when the whole apparatus was dropped has eliminated the compacting of the aggregates, and together with lightening the rods and driving weight, using three rods instead of one rod, and the use of a larger mold, has increased the precision of the tests. This apparatus is capable of measuring the influence of increased mixing time upon the workability, and measures the difference in workability of lean mixes with different gradations.

The studies are being continued.

NATURAL PROTECTIVE CRUST ON STONE.

A THEORY which has long been held by stone producers and many others concerned with the weathering of natural stone is that when the material is exposed to the weather a protective skin or crust is formed which tends to overcome the effect of the elements. For this reason it is often stated that cleaning methods such as sandblasting or any others which remove some of the surface of masonry will destroy this natural protective coating and materially shorten the endurance of the stone.

Some weathered samples of limestone were recently subjected to experiments at the bureau to determine if such a protective crust actually exists. One sample was a window sill from a building about 40 years old and another was a sill from a building about 30 years old. Two sets of specimens were prepared from each sample, one set having as one surface the weathered face of the stone as removed, and another having as one surface a face cut 4 inches below the weathered

face. These were tested for permeability, absorption, and abrasive hardness. Permeability tests were made under a water pressure of 100 lbs./in.^{2} and absorption tests were made in such a way that the water was absorbed only by capillary forces through one face of the slabs. In all tests the results indicated that stone near the weathered face was more absorptive, more permeable to water, and softer than the material 4 inches below this surface. The permeability of the specimens cut at the exposed face of the sample 40 years old was about twice as great as the permeability of specimens cut from the interior. Hardness tests indicated that the weathered surface was abraded about 50 per cent. faster than the unweathered stone.

"TRUE" DENSITY OF SEVERAL LIMESTONES USED IN THE MANUFACTURE OF LIME.

IN an investigation at the bureau on improvement in the manufacture of lime products it has been found necessary to make a study of some of the physical properties of several limestones. The properties considered were density, porosity, and crystal size. The careful determination of these properties, it is hoped, may, on completion of the work, give some index as to the optimum conditions to be imposed upon stone of different types in order to yield the most satisfactory products.

Density determinations have been made on 12 samples of stone, and in view of the limited amount of data of this nature available the results are herewith presented. The methods used were as follows: The rock samples were reduced to pass a No. 200 sieve. A weighed portion of the ground sample was placed in a calibrated picnometer which was then evacuated to a pressure of 10 mm. of mercury for 2 hours. While the picnometer was still evacuated, kerosene was added until the sample was submerged in that liquid. The picnometer was then filled to the calibration mark with kerosene at 25° C. and weighed. The density of the kerosene

was determined both under atmospheric conditions and for a period of 1/2 hour in vacuo. No appreciable difference was observed in the kerosene density under the two conditions. The above procedure was therefore considered sufficiently accurate, especially in view of the fact that the kerosene was exposed to vacuum over the sample for only 2 to 5 minutes.

The following table gives the results obtained:

Sample No.	Type.	Locality.	"True" density.	Sample No.	Type.	Locality.	"True" density.
1	High Ca	Mo.	2.788	8	Mg	Me.	2.882
2	High Ca	Va.	2.760	9	High Ca	Wash.	2.561
3	High Ca	Ohio	2.772	10	Dolo.	Ohio	2.694
4	High Ca	W. Va.	2.795	11	Dolo.	Ohio	2.383
5	High Ca	W. Va.	2.759	12	Mg	Pa.	2.844
6	Mg	Ohio	2.858	13	High Ca	Vt.	2.877

ARTIFICIAL VITRIFYING AGENTS FOR CERAMIC BODIES.

AN investigation is being conducted at the Columbus Branch of the bureau to determine the effect of artificial vitrifying agents in ceramic bodies. It is hoped by this investigation to lower the maturing temperature of a given body or to affect a greater vitrification and corresponding translucency at the same temperature. After a preliminary survey of the data available, the problem was attacked by choosing certain eutectic mixtures which deform below cone 5, 1,229° C. (2,245° F.). These eutectics, prepared as fritted glasses, constitute the source of the artificial vitrifying agents employed in the bodies.

The eutectics between the following materials were chosen: Feldspar-steatite; albite-calcite; sodium silicate-calcium silicate; albite-microcline; albite-magnesite; barium oxide-B_2O_3; calcium oxide-B_2O_3; barium silicate-sodium silicate; sodium silicate-magnesium silicate; microcline-albite-$CaO.Al_2O_3.SiO_2$; K_2O-SiO_2; K_2O-Al_2O_3-SiO_2; Na_2O-SiO_2; Na_2O-SiO_2-Al_2O_3; BaO-Al_2O_3-SiO_2; Na_2O-B_2O_3-SiO_2; K_2O-B_2O_3-SiO_2; Na_3AlF_6-Al_2O_3.

As a preliminary test, it was decided to make a cone deformation study which would also serve as a key to the degree of vitrification of the fritted bodies. Hence, the fritts were incorporated in a basic porcelain body composed of 16 per cent. feldspar; 10 per cent. No. 4 Kentucky ball clay; 35 per cent. English china clay; and 39 per cent. flint. Those fritts containing feldspar as one ingredient were added in amounts of 1, 3, and 5 per cent., all others being added in amounts of 10, 25, and 40 per cent.

These cones were fired in a down draft, gas-fired test kiln to cone 8. A brief summary of the first burn shows that complete deformation is obtained in 20 compositions containing 25 and 40 per cent. fritt, between the temperature of 1,060° C. (1,940° F.) (cone 05–04) and 1,290° C. (2,335° F.) (cone 8). In ten other compositions containing 10 per cent. fritt, complete vitrification was obtained, as evidenced by a much glassier texture and lower per cent. absorption than the standard body chosen.

It is evident therefore that the amount of body flux used can be diminished below 10 per cent. and that vitrification can be obtained at a temperature lower than that normally required. The fluxes, and the minimum amounts necessary to produce these desired properties, will be determined along with the effect these vitrifying agents may have on the physical properties of the given body.

CRAZING OF GLAZES CAUSED BY PERMANENT INCREASES IN SIZE OF CERAMIC BODIES.

THE bureau, in coöperation with the National Terra Cotta Society, is investigating the causes and remedies for delayed crazing of glazes for ceramic products and has developed a proposed method for testing glazes for this type of crazing.

In general there are two types of crazing which develop on glazed ceramic wares. One type is apparent upon removal of the ware from the kiln or it may develop a short time after removal. The cause of this type of crazing is well understood.

It develops when a glaze contracts more than the body in cooling from the temperature at which the glaze becomes rigid, down to room temperatures. Obviously this type of crazing may be prevented by selecting a glaze whose coefficient of expansion is the same as, or slightly less than, that of the body, so that the glaze contracts the same amount or slightly less than the body during cooling.

The second type, called "delayed crazing," may first develop a year or more after the ware has been fired, and heretofore its cause has not been well understood. It was thought at first that delayed crazing was the result of tension strains in the glaze which caused it to fail after a lapse of time, since these strains would produce fatigue of the glaze. However, upon investigation it was discovered that in many cases crazing developed on ware where the glazes were apparently free from strain or were in slight compression when the ware was removed from the kiln.

This discovery led to the belief that the body had probably expanded under normal atmospheric conditions while the glaze and vitrified portion beneath it remained constant, thus producing tensional strains in the glazed surface tending to cause crazing. Tests were, therefore, conducted to determine this point and the results to date indicate this to be the case.

It was found that certain bodies expand as much as 0.1 per cent. in length on storage while the glaze apparently remains constant and consequently cracking or crazing of the glaze develops. Bodies which do not develop this type of crazing do not show expansion on storage.

This increase in size of ceramic bodies is evidently due to combined water taken up from the atmosphere and the amount of this water increases in proportion to the increase in volume of the bodies.

Different methods for testing this type of crazing were investigated and the most promising one so far studied is the autoclave test. In this test it was found possible to produce in a few hours effects on the body and glaze similar to long

periods of storage. The specimens to be tested are placed in an autoclave, partly filled with water, and heat is applied so as to produce a steam pressure of 150–175 lbs./in.^{2} for one hour. The specimens are then removed and inspected for crazing by applying a malachite green or similar solution to the glazed surface to intensify the appearance of the craze markings. If the glaze does not craze after the autoclave treatment, it is probable that it will not craze in the future because of an increase in volume of the ceramic body.

In general the more vitreous bodies are less apt to develop this type of crazing than the more porous ones. It was also found that bodies having low solubility in sulphuric acid do not develop crazing as much as those of higher solubility. In general, bodies having low ignition losses above 110° C. after three or more years' storage develop less crazing than those having a high ignition loss.

It was found possible to prevent this type of crazing from developing by adding fluxes such as feldspar to the body during the manufacturing process and firing the product in the kiln to a temperature where the body becomes thoroughly vitrified.

MAKING THE GLASS FOR A TELESCOPE REFLECTOR.

THE successful casting of a large disk of optical glass at the bureau was briefly described in the February number of the bulletin. Some additional details may be of interest.

At first it was thought that this disk could be made by melting about 5,000 pounds of glass in one pot and cooling it in such a way that the pot would strip from the glass and leave the glass in one piece free from cracks. This procedure did not give satisfactory results.

Arrangements were then made to transfer the hot glass from the pot to a mold which would be at the same time an annealing furnace. The glass was melted in a pot specially prepared for this purpose at the bureau, and on May 7, 1927, the molten glass was transferred to the mold.

The mold consisted of a cast iron base and lid each 85 inches in diameter and 2 inches thick, separated by a ring 81 inches in diameter, 2 inches thick, and 19 inches high. The bottom and sides of the mold were lined with a very friable brick. This assembly was placed on a compacted layer of powdered diatomaceous earth which served as a thermal insulator, and finally the entire assembly was covered with the same material 12 inches in thickness. Plates containing high electrical resistance wires were placed between the cast iron and the insulation in such a way that uniform temperature could be obtained, and the temperature of the furnace could be controlled by varying the amount of current flowing through the resistors.

The maximum temperature noted in any part of the furnace immediately after casting the glass was 1,000° C. and, since there was no danger of the glass cracking at temperatures above 600° C., it was allowed to cool as rapidly as it would to this temperature which was reached in about eight days. Then by means of the electric heaters, this temperature was maintained for three days in order to obtain as uniform a temperature throughout the furnace as was possible. The glass was cooled slowly during two months from 600 to 460° C., at which temperature the glass was annealed for six weeks. Approximately five months were then required to reduce the temperature to that of the furnace room and, although the initial cooling rate from annealing temperature was approximately 1° per day, it finally reached a maximum of 6° C. per day.

The furnace was uncovered on January 21, 1928, and when the glass was examined it was found to be perfectly satisfactory for the purpose intended although it does contain some bubbles, striæ, and some very small pieces of pot shell.

The disk in its present condition is approximately 70 inches in diameter, 11 inches thick, and weighs about 3,750 pounds. When finished it will be 61 inches in diameter and 10 inches thick.

DENTAL RESEARCH AT THE BUREAU OF STANDARDS.

THE Bureau of Standards entered the dental research field in 1918 when a number of tests on dental amalgams were conducted at the request of the War Department. At that time, on account of the lack of sufficient funds, the bureau was not in a position to continue or extend the research to the other materials used in dental prosthesis although the necessity for such work was clearly indicated.

On January 16, 1922, a coöperative research on these materials was entered into with the Weinstein Research Laboratories, of New York City. This research has been carried on in accordance with the plan [1] authorized by Congress on April 12, 1892, and March 3, 1901. The specific problems included in this coöperative program were announced to the profession in 1924.[2]

Numerous progress reports [3] on the individual items of this program have been issued as the data were secured. From these it will be seen that the object of the research, namely, to establish the physical properties of certain dental materials included within the scope of this program and methods for testing materials designed for similar uses which may be developed in the future, has been accomplished and the results given to the profession and to all others interested. Dental schools and testing laboratories may now select

[1] Circular of the Bureau of Standards No. 296, "Research Associates at the Bureau of Standards." Available from the Superintendent of Documents, Government Printing Office, at 10 cents per copy.

[2] *Journal of the American Dental Association*, 11, pp. 249–250; March, 1924.

[3] "Wrought Materials. Methods of Testing, Values, Compositions," *Journal of the American Dental Association*, 12, pp. 509–546; May, 1925.

"Cast Materials. Methods of Testing, Values, Compositions," *Dental Cosmos*, LXVIII, pp. 743–764; August, 1926.

"Selection of Materials. Casting to Dimensions, Need for Testing," *Journal of the American Dental Association*, 14, pp. 189–199; February, 1927.

"Casting Materials. Physical Properties, Methods of Testing," *Dental Cosmos*, LXIX, pp. 1007–1026; October, 1927.

"Analysis of Dental Gold Alloys. Methods of Analysis," Bureau of Standards Scientific Paper No. 532. Price, 10 cents. (To be reprinted in *Journal of Dental Research*, VII; December, 1927.)

"Dental Gold Alloys. Tentative Specification and Test Methods," *Journal of the American Dental Association*. (In press, to appear in 1928.)

materials appropriate for the definite types of restorations and be assured of a safe method for manipulating the materials selected.

The coöperating laboratory has made it possible for the bureau to complete this work and, although the time required has been six years instead of two or three as anticipated in 1922, the Weinstein laboratories have never hesitated to maintain a sufficient number of research associates at the bureau and to bear their part of the expenses necessarily incurred. A conservative estimate of these items places the cost of the research to the coöperating laboratory at $50,000.

Recently, when this research was being completed, the Weinstein laboratories expressed their willingness to prepare a new program to include additional items and problems of interest to the profession. In view of the most satisfactory relations during the last six years it is certain that this work could have been successfully arranged and carried out in this manner, and the bureau very much appreciated this offer.

However, another proposition had also been received, from the American Dental Association through its research commission, and this was also being given consideration. This organization, commending the work already done, offered to share expenses in the carrying on of the new research program. Inasmuch as this offer was made by the organized profession and at the time when the original program was completed, it appeared that this offer of coöperation rather than the one from the Weinstein laboratories should be accepted. Therefore, the bureau has decided to proceed in this manner, and the new research program will be carried on hereafter in coöperation with the American Dental Association. It is felt that this enlargement of the scope of the investigation is necessary and proper and that the burden of financing this coöperative program may appropriately rest upon the individuals for whose benefit the work is being carried on.

The bureau has, in fact, been in communication with the American Dental Association in regard to the matter of a coöperative research since September 27, 1921, but prior to

1928 the Association has not seen its way clear to coöperate, financially, in this work.

The full coöperation of all parties interested in this new program is anticipated. Suggestions regarding the Association's part in this work should be made through its research commission. Communications should be addressed to Dr. L. L. Barber, Toledo, Ohio, chairman of the special committee representing the American Dental Association in this research.

TESTS OF PIEZO OSCILLATORS.

TESTS of radio devices by the Bureau of Standards are necessarily limited to special tests for the Government, tests of instruments which are in turn used as standards for testing considerable numbers of other instruments, tests of importance to the bureau as a matter of research, and a few other tests for which special reasons arise.

The bureau has considered transmitting station frequency standards as in the latter class, because of the great importance of insuring that all stations be adjusted to the same frequency basis, and because no laboratories doing commercial testing for the public have had standards or experience such as to insure that their measurements would meet this requirement. The demand for the testing of station frequency standards has increased to the point where the bureau cannot meet the demand under its present appropriations and facilities. Pending the completion of testing at present on hand, the bureau must for the present put applications for test of station frequency standards on a waiting list. Such tests may be made subsequently as circumstances permit. The bureau may eventually discontinue the testing of station frequency standards entirely, but does not expect to do this until it is satisfied that commercial organizations can handle the work satisfactorily. In the meantime the bureau desires to assist such organizations to prepare to do such testing.

The only kind of radio frequency standard at present commercially available which can be relied upon to an

accuracy better than 0.1 per cent. is the piezo oscillator. In the present state of development of this device, the bureau finds that the standardization of each one is a research job rather than a routine test. This has necessitated an increase in the fees charged; the new fees are given below.

A quartz plate will not be tested unless it operates readily, is mounted in a suitable holder, and is accompanied by the piezo oscillator circuits in which it is used.

Some quartz plates submitted are unsatisfactory for certification by reason of failure to operate, having one or more frequencies close to the desired frequency, or having a frequency outside the 1 per cent. limit set by the bureau. In case this is ascertained before the complete procedure of adjusting the plate is carried through, schedule 163*z* applies; half of the regular fee is usually charged. In case the unsatisfactory condition does not appear until the adjustment procedure is completed, the entire fee will be charged. These fees will be charged independently of whether another plate is submitted later.

Item.	Description.	Fee.
163*a*	Determination of one fundamental frequency of a piezo oscillator or resonator or quartz plate, at room temperature	$15.00
163*b*	Determination of one fundamental frequency of a piezo oscillator or resonator or quartz plate, provided with a suitable thermostat, at a specified temperature above that of the laboratory	25.00
163*c*	Adjustment at room temperature to specified frequency, of a quartz plate mounted in a holder provided with a simple mechanical adjustment for varying the frequency	20.00
163*d*	Adjustment at a specified temperature above that of the laboratory to specified frequency, of a quartz plate provided with a suitable thermostat and mounted in a holder provided with a simple mechanical adjustment for varying the frequency	40.00
163*e*	Adjustment at room temperature to specified frequency, of a quartz plate cut to approximate frequency (not more than 1 per cent. below the specified frequency)	30.00
163*f*	Adjustment at a specified temperature above that of the laboratory to specified frequency, of a quartz plate provided with a suitable thermostat and cut to approximate frequency (not more than 1 per cent. below the specified frequency)	75.00
163*z*	For special tests not covered by the above schedule, fees will be charged dependent upon the nature of the test.	

The Photochemical Union of Hydrogen and Chlorine. LOUIS HARRIS. (*Proc. Nat. Acad. Sciences*, Jan., 1928.) Kornfeld and Mueller in 1925 published their result of obtaining a yield of 10^4 molecules of HCl per light quantum. In the present investigation great care was exercised to avoid stopcock grease, mercury vapor and other gaseous contamination. "Chlorine was freed of oxygen, by washing a sample of fractionally distilled liquid chlorine, maintained at $-78°$ C., with electrolytic, purified hydrogen, for a period of six weeks." The quartz reaction vessel was illuminated with light of wave-length exceeding 4,050 Å. The most sensitive mixture of hydrogen and chlorine yielded in a second under the action of the light 6.27×10^{18} molecules of HCl. Per light quantum this is a minimum production of 6×10^5 molecules of hydrogen chloride. G. F. S.

Second Exposition of Industrial Heating in Paris. (*Chaleur & Industrie*, January, 1928.) The second Congrès du Chauffage Industriel, it is announced, will be held in Paris from June 23 to July 8, 1928. During this convention, an exposition of industrial heating will be held at the Parc des Expositions of the city of Paris. Exhibits will be displayed partly indoors and partly outdoors where apparatus in actual operation may be demonstrated. Exhibitors of any nationality are eligible to participate.

The exhibits will include those types of apparatus which are employed in the preparation and elaboration of solid, liquid or gaseous fuels, to the efficient utilization of heat and its control, the utilization of steam and the technique of firing, all in their relation to their industrial applications. This exposition which embraces every branch of industrial heating will be much more important than the one held in 1923 in that it will include a complete representation of improvements which have taken place during five years in the *materiel* of thermic industry.

All requests for information should be addressed to Commissaire Général, M. Charles Compère, Administrateur-Délégué-Directeur de l'Association Parisienne des Propriétaires d'Appareils à Vapeur, 66, rue de Rome, Paris 8e. L. E. P.

NOTES FROM LIGHTING RESEARCH LABORATORY, NATIONAL LAMP WORKS OF GENERAL ELECTRIC COMPANY.*

VISUAL ACUITY UNDER THE MERCURY ARC AND TUNGSTEN FILAMENT LAMP.

By M. Luckiesh and F. K. Moss.

It has been shown experimentally that, for low intensities of illumination, visual acuity is better for monochromatic light than for light of an extended spectral character. However, when the quality of the light only approaches monochromatism, such as the light from the mercury arc, there are reasons for doubting that it may have appreciable advantage in increasing visual acuity over an illuminant possessing a continous spectrum. The restriction of the spectrum, in itself, aids in reducing chromatic error and may improve visual acuity. On the other hand, it has appeared that monochromatic light from the ends of the visible spectrum is less favorable to visual acuity than that from the mid-region. Hence, the presence of the blue and violet in the mercury arc should be unfavorable. Whether or not the mercury-arc light is better, on a basis of visual acuity, than light from a tungsten filament will depend on the magnitudes of these opposing factors, granting that either is of significant effect.

Recently we investigated the matter directly by comparing these two illuminants, under identical conditions, as to their effect on visual acuity or sharpness of vision. Visual acuity is expressed in terms of visual angle or the angle in minutes subtended at the eye by the smallest perceptible object. A visual angle of one minute is represented by an object 0.0041 inch in size at a distance of 14 inches from the eyes. Visual acuity is greater as the visual angle of the object is less and *vice versa*.

We have summarized 6,000 observations made by ten adult persons under three intensities of illumination. Each

* Communicated by the Director.

person made observations on five different days. The measurements of foot-candles were made according to best practice in color-photometry. The average least visual angle perceptible is presented in minutes for the various conditions.

Illuminant.	5 foot-candles.	25 foot-candles.	125 foot-candles.
Mercury Arc	0.753	0.700	0.687
Tungsten-Filament Lamp	0.750	0.717	0.695

It will be noted that there is a progressive improvement in visual acuity for both illuminants as the intensity of illumination is increased. This is in agreement with our more extensive investigations and in this case, established the vital fact that our method was capable of measuring small differences in visual acuity. However, with other conditions equal, the differences in visual acuity obtained under the two illuminants are negligible.

WHITE LIGHT VERSUS NORTH SKYLIGHT FOR COLOR-DISCRIMINATION.

By M. Luckiesh,

Director of Laboratory.

IN the development of artificial lighting a propitious stage has been reached for exploding the tradition that north skylight is the best quality of light for the discrimination of color. In the past, when artificial light was entirely unsuited for color-discrimination, those interested in color chose north skylight because it was more nearly constant in quantity and quality than light from any other region of the sky. Hence it has become traditional to consider it the standard of daylight. Unfortunately, this so-called standard is quite variable in intensity and spectral character from hour to hour and from day to day.

The illuminant most suitable for color-work is one which does not favor any particular color. White light is the only

illuminant satisfactory in this respect. Spectrally, it is practically identical with noon sunlight on a clear day when the sun is at a high altitude. In white light the radiant energy is nearly equal in amount for all wavelengths throughout the visible spectrum. Since north skylight from a clear sky is quite bluish, it makes the purples (pink, lavender, magenta, etc.) appear more bluish than they would appear in white light. Because of its deficiency in yellow, orange, and red, north skylight suppresses these colors in objects illuminated by it.

The first satisfactory artificial-daylight glass for use with tungsten lamps was developed about fifteen years ago. Two qualities of daylight were reproduced—north skylight and noon sunlight. Those who developed artificial daylight found it necessary to supply a quality of light simulating north skylight because of the firmly intrenched habit of using north skylight for color-work. Here is one of the many cases where what people want and what is best are two different things. Inasmuch as color-discrimination does not involve taste, it seems that science rather than habit should dictate what the illuminant should be for general color-work.

To produce artificial north skylight with tungsten lamps it is necessary to absorb about 85 per cent. of the light. However, to produce white light corresponding to noon sunlight on a clear day in summer, an absorption of only 60 per cent. is necessary. In other words, white light—the only illuminant which is scientifically sound for color-discrimination—can be produced with tungsten lamps at nearly three times the efficiency of artificial north skylight.

REFLECTION-FACTORS OF PORCELAIN ENAMEL AND VARIOUS METALS.

By A. H. Taylor.

DURING the past five years we have made measurements of the diffuse reflection-factors of many metals and enamels. The measurements were made by use of a Taylor absolute

reflectometer,[1] which measures the light diffusely and specularly reflected when the light is incident on the specimen at an angle of approximately 30° to the normal. The results of these measurements show that the reflection-factor of some metals is very appreciably influenced by the method of preparation, and probably in part by their purity. The largest number of specimens measured have been aluminum, and they show large differences between different specimens. The table below summarizes the results of some of our tests on certain surfaces of interest.

DIFFUSE REFLECTION-FACTORS.

Material.	No. of Specimens Measured.	Reflection-Factor.	
		Range.	Average.
Porcelain enameled metal	3	72 to 77%	74%
Aluminum sheets	60	55 to 84	68
Cadmium-plated metal	5	50 to 74	64
Chromium-plated metal	3	63 to 66	64
Monel metal	1		49
Nickel-plated metal	4	61 to 65	63.5
"Nickeloid"	7	59 to 78	71
Silver-plated metal	2	90 to 91	90.5

All these surfaces were polished or otherwise prepared, by those submitting them, with the object of utilizing them for light-reflecting devices.

[1] B. S. Scientific Paper No. 405. *Trans. I. E. S.*, 15, p. 811, 1920.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

A TRIAL AND ERROR METHOD OF PREPARING A MOTION PICTURE SENSITOMETER TABLET.[1]

By C. E. Ives and J. I. Crabtree.

A SENSITOMETER is an instrument for determining the correct exposure when printing a positive film from negatives. With one type of this instrument a series of increasing exposures are impressed upon the negative through a sensitometer tablet, which consists of a series of areas of the same size as a motion picture frame and of such densities that the light transmitted by them is proportional to the intensity of the various light change steps on the printer. Previously, it has been possible to prepare such a sensitometer tablet only with the aid of precision instruments.

To construct a tablet by trial and error methods the printer is first checked for uniformity by examining about two feet of motion picture positive film "flashed" by running it through the printer without a negative and then developing to an average degree.

From a stock of flashed strips of varying density the tablet steps are chosen by matching with a set of test strips exposed on the printer at all the printer light change steps and developed under controlled conditions. The difference in density between the test strips for any two light change steps will be equal, approximately, to the density difference between corresponding tablet densities. If the first and last tablet are chosen in this way, a tentative tablet can be assembled by selecting, for the intermediate steps, samples of film, each of which increases in density from the next by a uniform density difference.

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* Communicated by the Director.

[1] Communication No. 324 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.* 11: No. 32, 740. 1927.

Each of these tentative tablet steps is compared with the corresponding printer step by making a print from a good negative on the printer and sensitometer and developing them together. If the two prints do not match exactly, a slightly greater or less dense sample of film is substituted in the tablet. This process is repeated until agreement is reached.

The sensitometer lamp is tested from time to time by comparison of prints made from the same negative on the printer and sensitometer.

OIL SPOTS ON MOTION PICTURE FILM.[2]

By G. E. Matthews and J. I. Crabtree.

THE presence of oil on motion picture film previous to development or during drying produces markings on the processed film having the general shape of the globules or smears of oil. The appearance of the markings produced is independent of the nature of the emulsion or the kind of oil commonly used on cameras, printers, or processing machines. The spots are more pronounced if film is exposed after it is coated with oil because each oil spot acts as a negative. The manipulative treatment which the film receives and the time elapsing after access of the oil and previous to processing greatly influences the appearance of the markings.

In the case of unexposed film certain types of oil produce a fogging effect and cause dark markings if left on the film several weeks but with exposed film the oil acts as a resist during development and produces a spot or patch of lighter density than the surrounding area. Also, since a greasy emulsion surface has a high propensity to accumulate airbells on immersion in a developer, many oil spots have circular white centers caused by the protective action of such airbells. By gently brushing the surface of the film during the initial stages of development, the airbells may be dislodged

[2] Communication No. 325 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.* 11: No. 32, 728. 1927.

but this is possible only when film is developed on a continuous processing machine. A classification of various markings is given.

The most satisfactory method of eliminating oil from the surface of motion picture film and therefore of preventing the formation of oil spots is to immerse the film in a bath of benzene or carbon tetrachloride, squeegee, and dry thoroughly previous to development. Suggestions are included on methods of lubrication of machinery for handling motion picture films.

BEHAVIOR OF GELATIN IN THE PROCESSING OF MOTION PICTURE FILM.[3]

By S. E. Sheppard.

To retain its photographic record, motion picture film must be a material of certain mechanical stability. Its mechanical behavior is largely determined by its composition as a union of higher water-absorbing gelatin with a slightly water-absorbing cellulosic colloid. The swelling and shrinkage of gelatin, though they be of secondary importance for the behavior of film in the theater, are of the first moment for its treatment in the laboratory, since they affect the durability of the film and even the character of the image. The swelling and shrinkage of gelatin may be considered from two viewpoints. There is the total expansion and the partial expansion in a given direction, involving temporary or permanent deformation. While the former has interested chemists, the latter is of equal or greater importance for photographers. In solutions of varying acidity or alkalinity gelatin shows a point of minimum swelling, termed the isoelectric point. On one side of this point swelling increases with alkalinity, on the other with increasing acidity, but in either acid or alkaline solutions swelling is repressed by most neutral salts. Advantage is taken of this in preparing solutions for processing under tropical conditions.

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[3] Communication No. 326 from the Kodak Research Laboratories and published in *Trans. Soc. Mot. Pict. Eng.* 11: No. 32, 707. 1927.

The swelling of gelatin, however, is not solely determined by its environment; it has, also, a heredity. Gelatin dried from dilute jellies will swell again in water much further than gelatin dried from concentrated jellies. Gelatin like other colloids has a rudimentary memory. Below a certain temperature gelatin swells in water up to a limit, but at higher temperatures it will swell without limit, finally breaking up. Limited swelling means that the elastic limit has not been passed, and the gelatin not permanently deformed. Although gelatin in motion picture film, by reason of its adhesion to the support, can swell only perpendicularly to the support, it has a tendency to swell sideways also, and when the total swelling becomes excessive or unlimited, this lateral swelling force promotes frilling and floating off of the gelatin. In passing other processing baths the gelatin is alternately swollen and shrunk, quantitative measurements on which are given in the paper, which stress the necessity for uniform conditions and procedure in processing. The drying of gelatin, process inversed to swelling, also strains the material; measurements are given in the paper showing the difference in contractile tendency in gelatin, the factor producing curling, warping, and stripping.

It is concluded that all conditions producing excessive swelling should be avoided, as by adjusting the developer to limit the swelling, by avoiding excessive alkali and acid in processing baths, by uniform temperature of processing baths and wash waters, when possible by keeping the temperature down below a certain limit, and by avoiding excessive washing.

NOTES FROM U. S. BUREAU OF MINES.*

INVESTIGATION OF RAILWAY TUNNEL ATMOSPHERES.

An investigation of atmospheres in certain railroad tunnels, recently conducted by the United States Bureau of Mines, Department of Commerce, disclosed that high temperature and humidity conditions were responsible for some discomfort to enginemen, but that the percentages of carbon monoxide and other harmful gases were not dangerous so long as trains are kept moving through the tunnels.

At the request of the railway company, a number of tests were made to determine the temperature, humidity, and composition of the atmosphere in various tunnels. Tests were made of two types of locomotives, classified by the railroad company as the H-6 and H-7. Both are of the Mallet type, but the H-6 class has one pair of cylinders operating at boiler pressure and the other pair compound, whereas the H-7 operates all four cylinders at boiler pressure, thereby exhausting steam at a higher temperature than the H-6. It was desired to determine the relation between conditions on the H-6 and H-7 engines under comparable conditions of operation. Three incidental tests of passenger engines were also made.

Temperature measurements were taken in the tunnels with a wet and dry bulb thermometer of the sling type, and samples of the atmosphere were obtained for determination of the carbon monoxide, sulphur dioxide, carbon dioxide, and oxygen. These temperature measurements and gas samples were taken in the engine cab near the engineman or fireman. Several qualitative tests for hydrogen sulphide were made, but all were negative. On several occasions, blood samples were taken from one of the members of the test crew as soon as

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possible after emerging from the tunnels. None of these samples showed any significant degree of saturation with carbon monoxide.

Of all the tests only two showed any appreciable amount of carbon monoxide, and this in amounts that would have no dangerous effects unless exposure was for 45 minutes or longer, state Dr. R. R. Sayers, L. B. Berger, and W. P. Yant, in the report of the investigation, published as Bureau of Mines Serial 2858. There was no health hazard from sulphur dioxide, carbon dioxide, or depletion of oxygen content of the atmosphere for the time of exposure in these tests. There would be danger from the gases found only if a train was stopped while in a tunnel.

The chief cause of discomfort was the high temperature and humidity. In one test the temperature was high enough to cause a surface burn. A similar test, with the engine worked under a lighter throttle, gave conditions that caused no marked discomfort, showing the relation that train manipulation bears to the conditions in the tunnels.

The conditions of temperature and humidity as found on these tests were somewhat more severe on the H-7 engines than on the H-6 type, but only in two cases did conditions approach a degree of severity that might be termed unbearable.

Although many of the effective temperatures recorded were above those that would be practicable for long exposure, men are able to work for short periods—10 to 15 minutes—without marked inconvenience. An exposure of one hour to 98° with 100 per cent. relative humidity causes the pulse-rate to be greatly increased, as well as causing a marked increase in body temperature and body metabolism, even when the individual remains at rest.

The maximum endurance found at 105° saturated air is approximately 45 minutes and at 117° the limit of endurance is 15 minutes; 135° effective temperature could not be borne for any length of time by a man with the skin directly exposed. Thick clothing will protect or, in other words, will insulate the body from such temperatures. Work has been performed

at 135° effective temperature by using special suits of thick felt. Under these circumstances work has been performed for 15 to 20 minutes. It is noted that because of this clothing insulation the unclothed body is not actually exposed to the temperatures.

MAKING CAST IRON IN THE ELECTRIC FURNACE.

Although the cupola is the cheapest melting device for the production of molten iron under normal market conditions for pig iron, coke and clean cast-iron scrap, there are conditions under which expense of melting is not the major factor, so that certain other advantages possessed by the electric furnace sometimes make it more desirable. A comprehensive investigation of the making of electric-furnace cast-iron has been completed by the Bureau of Mines at its Northwest Experiment Station, Seattle, Washington, in coöperation with the College of Mines, of the University of Washington. The investigation involved a year's successful operation of a jobbing foundry making miscellaneous gray-iron castings from steel scrap.

Under the special conditions that make the electric furnace advantageous, this type of furnace need not necessarily displace the cupola but can be used in conjunction with it. The ability of the electric furnace, and not of the cupola, to refine and to superheat iron and the superiority in many ways of electric-furnace iron to cupola iron make the electric furnace advantageous under special conditions. In addition, the possibility of producing electric-furnace cast iron from cheap grades of ferrous scrap has brought the electric furnace into prominence.

Electric-furnace cast iron is stronger, tougher, and more dense than cupola iron, and a higher recovery of metal in casting can be obtained as a result of the higher pouring temperature, state C. E. Williams and C. E. Sims, in Technical Paper 418, just issued. Cast-iron scrap of high-sulphur content can be converted into high-grade cast iron, low in sulphur, either by melting directly in the electric furnace or by

refining molten metal from the cupola. Large additions of steel scrap may be used if desirable, or steel scrap can be used entirely and synthetic cast iron made. Some of the advantages of the production of synthetic cast iron are outlined below.

One electric furnace can be used to produce both iron and steel and can thereby be kept in operation during periods when it might otherwise be idle. By operating an electric furnace continuously labor is kept usefully employed, the heat of the furnace is conserved, life of the refractories is extended, overhead charges are reduced, and a high load factor on the power lines is maintained. Therefore, even under conditions where production of synthetic iron would not of itself be economical, it might be profitable in conjunction with the making of steel, because of the possibility of reducing the cost of producing steel.

A large variety of steel and iron scrap can be used to make the same product, and many different products can be made from the same materials. As a rule, scrap is purchased locally, and the foundryman can buy and use what is at hand without shopping around for special materials. The production of synthetic iron in a steel foundry simplifies the purchase of steel melting scrap. For instance, the making of acid steel requires selected scrap, for which a higher price must be paid than for general scrap; but if, in addition to steel, synthetic iron is made, miscellaneous steel scrap may be purchased at a minimum price and the foundryman can do his own sorting, using the best scrap for acid steel.

Synthetic iron may be tested and adjusted for composition and temperature before it is poured, thus assuring castings of the desired composition. Moreover, if the pouring crew is not ready, the metal can be kept hot as long as necessary, whereas metal must be taken from the cupola when enough has been melted to pour.

In the electric furnace a superior iron, having about twice the strength of ordinary cupola iron, can be made. Transverse strengths of 5,000 to 6,000 pounds on standard bars of

synthetic gray iron have been repeatedly obtained, and tensile strengths above 40,000 pounds per square inch are common. One of the outstanding characteristics of electric-furnace gray-iron is its resistance to impact of shock. These advantages in strength and toughness are due largely to the physical structure of the iron, which is fine-grained and dense. The graphite exists in such small flakes that a piece of synthetic iron of the same graphitic carbon content as a piece of cupola iron will appear to contain less graphite. Although it looks whiter and harder than cupola iron, synthetic iron is soft and easily machined. A coarse-grained synthetic iron can be obtained only when the carbon and the silicon contents are exceptionally high. Ordinary synthetic iron is at least equivalent in strength to the so-called high-test irons and semisteels of the cupola.

Virtually any kind of ferrous scrap can be used in the electric furnace, thus providing a means for industrial plants to utilize the scrap they produce instead of shipping it away at an economic loss. Besides steel scrap, which may be carburized to gray iron, gray-iron borings and light scrap may be used profitably.

The production of synthetic cast iron in the electric furnace is advantageous in such places as large nonferrous smelters and mills, where pig iron is expensive and ferrous scrap is usually available. Many ore-concentration plants consume a large tonnage of steel and iron balls and ball-mill liners for fine grinding, and satisfactory white cast iron for these purposes could be made economically at the plant.

A tough and hard white iron, such as may be produced in the electric furnace from steel scrap, will find useful application where resistance to shock and abrasion are required.

SEPARATION OF PHOSPHORUS, MANGANESE, AND IRON IN HIGH-PHOSPHORUS SPIEGEL.

Material suitable for the production of ferromanganese (80 per cent. Mn), according to present specifications, must

not contain more than 0.2 per cent. phosphorus. Although material containing more than 10 per cent. SiO_2 can be used, it requires more fuel and causes greater slag losses. Iron and manganese must be present in proper proportions.

Further tests have been made by the Bureau of Mines to determine whether high-phosphorus spiegel, made from manganiferous iron ore, can be treated in an open-hearth furnace so as to produce a slag which will meet the requirements of ferro grade ore. Additional tests have confirmed results previously obtained which indicated that oxidation of manganese will proceed if a slag contains between 25 and 35 per cent. FeO, even though it is not fluid throughout.

THE FRANKLIN INSTITUTE.

(Proceedings of a Special Meeting Held Thursday, March 15, 1928.)

A SPECIAL meeting of the Institute was called at eight-fifteen p.m. on Thursday, March fifteenth, upon the direction of Henry Howson, Esq., senior Vice-President, to consider and act upon the proposal of the Board of Managers to purchase the property 135 North Nineteenth Street, Philadelphia, in order to complete the plot for the proposed new buildings of the Institute.

The Vice-President outlined the negotiations, and stated that the purchase of the property was recommended by the Board of Managers.

It was then resolved, unanimously, that the Institute approve the purchase of the property 135 North Nineteenth Street, for the completion of the plot for the projected new buildings of the Institute, at a price of fifty thousand dollars.

There was no further business and the special meeting was thereupon adjourned.

HOWARD MCCLENAHAN,
Secretary.

(Proceedings of the Stated Meeting Held Wednesday, March 21, 1928.)

THE regular monthly meeting of the Institute was called to order at eight-fifteen p.m. by the Vice-President, Mr. C. C. Tutwiler.

The Secretary announced that the minutes of the monthly meeting held in February had been printed in full in the March number of the Journal and that, unless objection were offered, the minutes would be regarded approved as printed. No objection was heard.

The Secretary made a statement concerning the result of the special meeting held on March fifteenth, to consider the purchase of the property at 135 North Nineteenth Street. He stated that this proposed purchase was unanimously approved.

The Secretary made a statement concerning the meetings of the Institute scheduled for the balance of this year and referred especially to the celebration of the fiftieth anniversary of the world's first tests of a dynamo, which celebration will be held in the Hall of the Institute on April eighteenth, in the room where the original tests were made. He made a brief statement also concerning the plans for the Medal Day meeting to be held on May sixteenth.

The Chairman introduced, as the speaker of the evening, Dr. C. J. Davisson, of the Bell Laboratories, Inc., of New York, who read an important and stimulating paper on the subject, "Are Electrons Waves?" The paper was followed by an unusually active discussion, after which the meeting adjourned at nine-forty-two p.m.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, March 7, 1928.)

HALL OF THE COMMITTEE,
PHILADELPHIA, March 7, 1928.

DOCTOR GEORGE S. CRAMPTON *in the Chair.*

The following reports were presented for final action:

No. 2878: Work of Henry Ford.

This report recommended that the Elliott Cresson Medal be awarded to Mr. Henry Ford, "In consideration of his rare inventive ability and power of organization, by means of which he was able to effect high speed production of automobiles, revolutionizing the industry; and his outstanding executive powers and industrial leadership."

No. 2880: Work of Mr. Arthur Graham Glasgow in the Gas Industry.

This report recommended the award of the Walton Clark Medal to Mr. Arthur Graham Glasgow, of London, England, "In consideration of his outstanding and valuable work in the technology and development of the manufactured gas industry."

No. 2888: Composition of Super-Resistant Glasses.

These glasses, known under the name of Pyrex Glassware, were developed at the Corning Glass Works, Corning, New York.

This glassware is the result of an extended experimental research which produced a glass having high resistance to chemical attack, to heat and mechanical shock; low specific gravity with high electrical resistance and high transmission of the visible spectrum as well as of heat rays and ultraviolet radiation.

While the melting point is high, this glassware becomes sufficiently plastic at a slightly lower temperature to be pressed or blown into any desired shape.

It is in extensive use for laboratory glassware, baking utensils, electrical insulators for various radio and transmission uses and an increasing variety of other applications.

The award of the Howard N. Potts Medal was recommended to the inventors, Doctor E. C. Sullivan and Mr. W. C. Taylor, of Corning, New York.

No. 2891: Literature.

This report recommended the award of the Louis Edward Levy Medal to Mr. Vannevar Bush, for his two papers entitled "A Continuous Integraph" appearing in the January, 1927, issue of the Journal of The Franklin Institute and "Integraph Solution of Differential Equations" appearing in the November, 1927, issue of the Journal, with mention of his three collaborators, Messrs. H. L. Hazen, F. D. Gage and H. R. Stewart.

The following report was presented for first reading:

No. 2890: Wright Whirlwind Engine.

Prior to the development of the Wright Whirlwind Engine the water-cooled engine was used for airplanes. In 1916 Mr. Charles L. Lawrance began the development of air-cooled engines of small horsepower and from this beginning the present series of Wright Whirlwind Engines has been developed.

These are radial engines, having nine cylinders and developing 200 horsepower at 1,800 r.p.m.

They are extensively used in many types of airplanes and both their design and construction have combined to give them great endurance.

These engines have become generally known through notable flights that have been made recently. Of these the flight of Commander Byrd and his pilot Floyd Bennett from Spitzbergen to the North Pole and return, the solo flight of Colonel Charles A. Lindbergh to France and his later trip to the principal cities of the United States, then to Mexico and the Southern Republics and many others may be mentioned.

In this report the award of the Elliott Cresson Medal was recommended to Mr. Charles L. Lawrance, of Long Island, New York, "In consideration of his pioneer work in the development of the air-cooled airplane engine, of his skill in bringing this engine to a high degree of perfection and of his ability in carrying out its manufacture."

On motion, duly seconded, the Committee passed to the second reading of this report.

The following minute on the death of Doctor William C. L. Eglin was adopted:

"In the death of Doctor Eglin, the Committee on Science and the Arts of The Franklin Institute has lost a faithful member and one who has for many years rendered most valuable service. Doctor Eglin became a member of The Franklin Institute, May 21, 1891, was elected a member of the Committee on Science and the Arts on February 2, 1898, and remained a member until his death on February 7, 1928. During his connection with the Committee he rendered service not only as a member but as chairman of numerous sub-committees, his work always being distinguished by clear thinking and thoroughness.

"*Be it resolved*, That on the death of our fellow member, Doctor William C. L. Eglin, the Committee desires to record its acknowledgment of the valued services rendered by him as a member of the Committee on Science and the Arts. This Committee also desires to express its grateful appreciation of the sympathetic and cordial relationship that existed between him as President of The Franklin Institute and the Committee and its work.

"*Be it also resolved*, That the sympathy of the Committee be extended to his family in its bereavement.

"*And be it further resolved*, That a copy of these resolutions be sent to his family and be spread upon the minutes of the Committee."

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, March 14, 1928.*)

RESIDENT MEMBERSHIP.

MR. WILBUR G. DUNNING, Instructor in Chemistry, Temple University, Philadelphia, Pa. For mailing: Westtown, Pa.

MR. HENRY G. HART, Newspaper reporter, 917 Chestnut Street, Philadelphia, Pa. For mailing: 615 Shady Lane, Narberth, Pa.

MR. HUGH ERNEST HARTING, Instructor in Chemistry, Temple University High School, Philadelphia, Pa. For mailing: 6439 Clearview Street, Germantown, Philadelphia, Pa.

MR. ANTHONY A. HAUSSER, Manufacturer of medical instruments, 1326 North Nineteenth Street. For mailing: 117 West Luray Street, Philadelphia, Pa.

MR. ARTHUR V. MORTON, Vice-President, Pennsylvania Company Insurance on Lives and Granting Annuities. Southeast corner Fifteenth and Chestnut Streets, Philadelphia, Pa.

NON-RESIDENT MEMBERSHIP.

MR. WILLIAM ALDRICH, Traveling Engineer, South San Francisco, California. For mailing: 720 Pepper Avenue, Burlingame, California.

MR. DONALD LEWIS KELLOGG, Engineer in Development Work, Western Electric Company, Kearney, New Jersey. For mailing: 20 Pine Street, Cranford, N. J.

MR. RUDOLPH F. MALLINA, Head of Apparatus Development Division, Victor Talking Machine Company, Camden, New Jersey. For mailing: 178 States Avenue, Atlantic City, N. J.

DR. ROBERT E. ROSE, Chemist, Director, Technical Laboratory, Dyestuffs Division, E. I. duPont de Nemours and Company, Wilmington, Delaware. For mailing: P. O. Box 518 Wilmington, Delaware.

STUDENT MEMBERSHIP.

MR. EARL P. CARTER, Laboratory assistant, Victor Talking Machine Company, Camden, New Jersey. For mailing: 112 Cedar Avenue, Pitman, New Jersey.

MR. ROBERT HUTTON KAY, JR., Student, Motor Journalism, Temple University, Philadelphia, Pa. For mailing: 2346 North Park Avenue Philadelphia, Pa.

MR. CHARLES WILLIAM MOORE, Student, 46 North Sixty-second Street, Philadelphia, Pa.

CHANGES OF ADDRESS.

PROFESSOR LEE DAVIDHEISER, In care of Wagner College, Staten Island, New York.

MR. JOHN FERGUSON, 3702 Fall Creek Boulevard, Indianapolis, Indiana.

MR. GEORGE R. HALL, Room 2205–225 Broadway, New York City.

MR. EDWIN W. HAMMER, 80 John Street, New York City.

MR. ANDREW A. KUCHER, 2206 Valentine Avenue, New York City.

MR. NEWTON LAMB, 305 West Larkin Street, Midland, Michigan.

MR. J. W. MOOREHOUSE, JR., Office of Chief Engineer, Reading Terminal, Philadelphia, Pa.

DR. JACOB NEVYAS, 5822 Chestnut Street, Philadelphia, Pa.

MR. CHARLES H. NORDHAUS, 2216 North Melvina Avenue, Chicago, Illinois.

MR. RODOLPHO ORTENBLAD, Civil and Electric Engineer, The Rio de Janeiro Tramway, Light and Power Company, Ltd., Rio de Janeiro, Brazil.

KENNETH M. RITCHIE, ESQ., Armstrong Cork Company, Research Division, Lancaster, Pa.

DR. JESSIE A. RODMAN, 4933 Rubicam Street, Germantown, Philadelphia, Pa.

NECROLOGY.

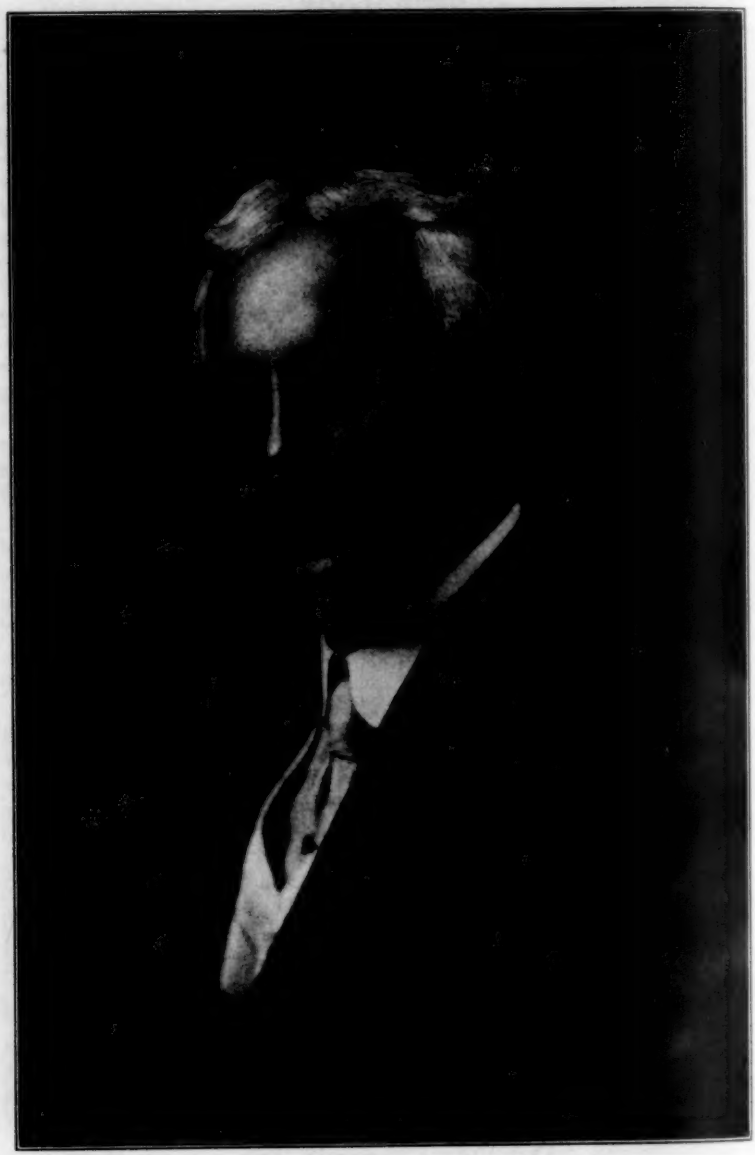
Alexander Ewing Outerbridge, Jr., was born in Philadelphia on July 30, 1850, and died on January 15, 1928. Mr. Outerbridge was educated at the Episcopal Academy and received private instruction in analytical chemistry and mathematics. In 1867 he was made assistant to Professor Henry Morton, then Secretary of The Franklin Institute and in the absence of Dr. John F. Frazer Professor of Chemistry and Physics at the University of Pennsylvania. During the following year Mr. Outerbridge conducted some of Professor Morton's classes and also taught English at the Episcopal Academy. In 1869 he was appointed Assistant in the Assay Department of the United States Mint in Philadelphia. Ten years later he was offered the position of Chief Assayer at the Assay Office at Helena, Montana, which he declined, and this was followed by a temporary transfer to the Mint at New Orleans, La., for the purpose of organizing the assay laboratory which was about to be re-established. He returned to the Philadelphia Mint in the following year. In 1881 he resigned his position at the Mint and became Metallurgist for Messrs. A. Whitney & Sons, manufacturers of car wheels. After eight years with this firm he accepted a similar position with William Sellers & Company, Inc., which he retained until the time of his death.

In 1873 Mr. Outerbridge conducted an extensive investigation by authority of the Director of the Mint in spectrum analysis of gold, silver and other metals, samples of which were supplied by the Assay Department. This study occupied a period of about eight months and was conducted in the Laboratory of the Assay Department of the United States Mint, at the Stevens Institute, Hoboken, N. J., and at the University of Pennsylvania. The results were embodied in reports to the Director of the Mint and afterwards incorporated in his Annual Report.

In 1876 Mr. Outerbridge discovered a process for obtaining extremely thin films of gold and other metals by electro-deposition on copper foil and subsequently dissolving the copper matrix, leaving the thin metal films floating intact. They were then mounted on glass slides and studied under high power microscopes by transmitted as well as by reflected light. Electro-films were obtained 1/10,000,000 of an inch thick. Mr. Outerbridge also conducted a series of experimental investigations on the impurities in silver. Special apparatus was devised and erected in the melting department of the United States Mint for collecting the metallic vapors escaping from the crucibles and recovering the precious metals therefrom. A summary of these investigations appeared in the JOURNAL OF THE FRANKLIN INSTITUTE for June 1879.

In 1886 Mr. Outerbridge discovered a process for carbonizing fern leaves and other organic products, lace and other delicate fabrics without making them brittle and employing these carbonized materials directly as "facings" in molds into which molten cast-iron, steel, bronze or other metals were poured, thus obtaining perfect replicas of the designs in metal suitable for dies and other purposes.

The results of a two years' study of the "mobility of molecules" of solid, cold cast-iron were made public in February 1896. The Franklin Institute appointed a committee to investigate the subject and after making a number of



ALEX. E. OUTERBRIDGE, JR.
1850–1928.

tests of bars published its report in July 1898. As a result of the above experiments Mr. Outerbridge also discovered that iron castings can be caused to grow in cubical dimensions while in the solid state without destroying their metallic properties or distorting the shapes. This subject was also considered by the Committee on Science and the Arts of the Institute; he was awarded the Elliott Cresson Medal. While investigating the hardening of steel tools Mr. Outerbridge devised an improved form of "permanent color screen" for readily ascertaining the exact temperature of a bath of molten metal. In 1911 Mr. Outerbridge made public a method for detecting the adulteration of certain oils by fluorescence.

Mr. Outerbridge has been a member of The Franklin Institute since 1871. He served on its Committee on Science and the Arts from 1875 to 1889, was a member of its Board of Managers from 1881 to 1886 and was an active member of the Committee on Exhibitions during the continuance of the International Electrical Exhibition in 1884. He was appointed Professor of Metallurgy of The Franklin Institute in 1901 and became President of the Mining and Metallurgical Section in 1908, serving up to the time of discontinuance of the Section. He was awarded the John Scott Medal by the City of Philadelphia on the recommendation of the Institute in 1888 for his method of carbonizing fabrics and castings therefrom and again in 1897 for his method of investigating the molecular physics of cast-iron. The Elliott Cresson Medal was awarded to him by The Franklin Institute in 1904 for his investigations in the molecular structure of cast-iron. His interest and activities were varied but he was always ready and willing to coöperate in any undertaking which might in any way benefit The Franklin Institute. A list of his contributions to the JOURNAL of the Institute covering a period of over forty years follows:

Advantages of mechanical stoking,
Alloys of silver with embrittling metals,
Application of spectroscope to mint assaying,
Casting iron, etc., on lace, embroideries, fern-leaves, etc.,
Dangers arising from the use of cast-iron in the construction of steel skeleton structures,
Edison electric light,
Electricity,
Equilibrium of iron-carbon systems (translation from the French),
Fourth state of matter,
Franklin Medal,
Future of American industries,
High-grade silicon for purifying cast-iron,
Integrity of tests of metals,
Lecture on matter, including "radiant" matter,
Machinery and the man,
Metallurgy and assaying of the metals used in coinage,
Mineral wealth of the islands of Newfoundland and Jamaica,
Mining and minting of gold and silver,
Modern traveling crane,
Molecular annealing of cast-iron,
Molecular changes in cast-iron caused by vibration,
The molecule, the atom and the new theory of matter,

Opening address, president of the Mining and Metallurgical Section,
Pending problems for wage earners,
Pig-iron, etc., etc.,
A practical application of fluorescence in testing oils for industrial purposes,
Recent investigations and discoveries in cast-iron,
Recent progress in metallurgy,
Science in the foundry,
Smoke nuisance and its abatement,
Some further notes on cast-iron,
Strength of white-iron castings as influenced by heat treatment,
Study of the micro-structure of bronzes,
Undeveloped wealth of Newfoundland,
Utilization of blast-furnace waste.

LIBRARY NOTES.

RECENT ADDITIONS.

Allen's Commercial Organic Analysis. Fifth edition, revised and in part re-written. Volume 6. 1928.

Amtorg Trading Corporation. Catalog of American Industry and Trade. (In Russian.) 1927.

ANDRADE, E. N. DA C.—Structure of the Atom. No date.

BELLUZZO, GIUSEPPE.—Les Turbines à Vapeur. Traduit de l'Italien par Jean Chevrier. Two volumes. Deuxième edition. 1927.

BLOCH, EUGÈNE.—Thermionic Phenomena. Translated by J. R. Clarke. No date.

BUSWELL, ARTHUR M.—Chemistry of Water and Sewage Treatment. 1928.

DICKINSON, H. W., AND RHYS JENKINS.—James Watt and the Steam Engine. 1927.

FRANKLIN, BENJAMIN.—Works . . . Consisting of His Life Written by Himself, Together with Essays, Humorous, Moral, and Literary, Chiefly in the Manner of The Spectator. Two volumes bound in one. 1794.

GAUSS, CARL FRIEDRICH.—Bestimmung der Anziehung eines elliptischen Ringes. Ostwald's Klassiker der exakten Wissenschaften Nr. 225. 1927.

HÜBL, ARTHUR.—Die Lichtfilter. Dritte Auflage. 1927.

JACOBI, C. G. J.—Theorie der elliptischen Funktionen aus den Eigenschaften der Thetareihen abgeleitet. Ostwald's Klassiker der exakten Wissenschaften Nr. 224. 1927.

Minerva Jahrbuch der gelehrten Welt. Neunundzwanzigster Jahrgang, Band I. 1928.

OSBORN, CHASE SALMON.—The Earth Upsets. (Another Terrestrial Motion.) 1927.

REILLY, JOSEPH, WM. N. RAE, AND T. S. WHEELER.—Physico-Chemical Methods. No date.

WIEN, W., AND F. HARMS.—Handbuch der Experimentalphysik. Band 6, Kapillarität und Oberflächenspannung, bearbeitet von G. Bakker. 1928.

BOOK REVIEWS.

Report No. 277, The Comparative Performance of an Aviation Engine at Normal and High Inlet Air Temperatures, by Arthur W. Gardiner and Oscar W. Schey. 19 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

This report deals with results obtained during an investigation to determine the effect of high inlet air temperature on the performance of a Liberty 12 aviation engine. The purpose of this investigation was to ascertain, for normal service carburetor adjustments and a fixed ignition advance, the relation between power and temperature for the range of carburetor air temperatures that may be encountered when supercharging to sea level pressure at altitudes of over 20,000 feet and without intercooling when using plain aviation gasoline and mixtures of benzol and gasoline.

Laboratory tests were made at full throttle over the speed range from 1,400 to 1,800 R.P.M., in which the pressure at the carburetor and exhaust was maintained sensibly constant and the inlet air temperature varied from 45° to 180° F. The range of mixtures was that normally used in flight. Plain aviation gasoline, a mixture consisting of 30 per cent. (by volume) of commercial benzol and 70 per cent. gasoline, and a mixture of 65 per cent. benzol and 35 per cent. gasoline were used. Additional tests were made with a Wright E-4 aviation engine.

The results show that for the conditions of test both the brake and indicated power decrease with increase in air temperature at a faster rate than given by the theoretical assumption that power varies inversely as the square root of the absolute temperature. On a brake basis, the order of the difference in power for a temperature difference of 120° F. is 3 to 5 per cent. The observed relation between power and temperature when using the 30–70 blend was found to be linear. But, although these differences are noted, the above theoretical assumption may be considered as generally applicable except where greater precision over a wide range of temperatures is desired, in which case it appears necessary to test the particular engine under the given conditions.

Report No. 279, Tests on Models of Three British Airplanes in the Variable Density Wind Tunnel, by George J. Higgins, W. S. Diehl, and George L. DeFoe. 27 pages, illustrations, quarto. Washington, Government Printing Office, 1928. Price, fifteen cents.

Results of tests made in the Committee's variable density wind tunnel on three airplane models supplied by the British Aëronautical Research Committee are here given. The models, the BE-2E with R.A.F. 19 wings, the Bristol Fighter with R.A.F. 15 wings, and the Bristol Fighter with R.A.F. 30 wings, were tested over a wide range in Reynolds Numbers in order to supply data desired by the Aëronautical Research Committee for scale effect studies.

The maximum lifts obtained in these tests are in excellent agreement with the published results of British tests, both model and full scale. No attempt is made to compare drag data, owing to the omission of tail surfaces, radiator, etc. from the model, but it is shown that the scale effect observed on the drag coefficients in these tests is due to a large extent to the parts of the models other than the wings.

FUNDAMENTALS OF DAIRY SCIENCE. By Associates of Lore A. Rogers in the Research Laboratories of the Bureau of Dairy Industry, United States Department of Agriculture. 543 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1928. Price, $5.50.

The jubilee volume has been more in evidence in Germany than in other nations. The Festschrift is frequently presented in commemoration of a quarter-century or a half-century of service in some department of human knowledge. The Anglo-Saxon is not quite as effusive in recognition of merit and we have had in the United States but little of this type of publication. The present volume does not prominently appear as a jubilee book but the dedication to Lore Alford Rogers in recognition of his quarter-century service in the advancement of knowledge both in its pure and applied phases indicates it as a work of the commemorative type. The subject matter of the book is entirely that of dairy chemistry. It is one of the publications under the auspices of the American Chemical Society, so many of which have already been given to the public. The contributions are by those who have served with the dedicatee, whose portrait is given as a frontispiece.

A vast amount of information concerning the chemistry, physical chemistry, microbiology and nutritional value of milk and milk products is contained within the volume. The first section of about a hundred pages is devoted to the constituents of milk, each set of constituents being given a special chapter. Even subdivisions of these chapters are by separate authors, specialists in the various fields treated. Naturally, cows' milk in its sanitary and economic relation occupies the most prominent position. It is not a manual of analysis but brings up to date the nature and value of milk as a food. As the contributors are American workers, it is another evidence of the commendable development in pure and applied science which is taking place in this country and the contributors deserve great credit for the plan of thus combining in one convenient volume the results of their investigations on the topics covered. It is indeed astonishing to see how a single article of food can be properly treated in such extent and detail.

HENRY LEFFMANN.

THERMIONIC PHENOMENA. By Eugène Bloch, Maître de conférences à la Faculté des Sciences, Paris. Translated by J. R. Clarke, M.Sc., F.Inst.P., Lecturer in Physics in the University of Sheffield. x–145 pages (18 x 12 cm.), cloth. New York, E. P. Dutton and Company. Price, $2.50.

The advent of the Fleming valve and its subsequent evolution into an appliance of capital importance in telephony, both over wires and through the air, marks an epoch of intensive research in thermionic emission. The characteristics and capabilities of the thermionic tube are both understood by many as well as intelligently used by a much greater number, yet the basic principle, thermionic emission, upon which it operates still constitutes a fruitful field for research. Those who would keep abreast with the continued advance in this art as well as with the general problem of electrical conduction in the proximity of heated bodies must keep themselves informed on the numerous investigations which are continually accumulating in the files of scientific societies and occasionally appearing in book form. To such readers Professor Bloch has provided

by the issue of this volume a labor-saving work of great value. Within its covers will be found a resumé of all the important studies which have been made in modern times on thermionic emission. The work is most thoroughly documented from English and American and French and German sources. Most notable among these is the work by O. W. Richardson, "The Emission of Electricity from Hot Bodies" the latest edition of which appeared in 1921. The excellent rendition into English by Professor Clarke is a worthy setting for a book of timely value.

LUCIEN E. PICOLET.

PROPERTIES AND TESTING OF MAGNETIC MATERIALS. By Thomas Spooner, Research Engineer, Westinghouse Electric and Manufacturing Company; Chairman of the Magnetic Properties Committee of the American Society for Testing Materials; Member American Institute of Electrical Engineers; Member American Physical Society. xiv–385 pages, 23 x 15 cm., cloth. New York, McGraw-Hill Book Company, Inc., 1927. Price, $5.

APPLIED MAGNETISM. By T. F. Wall, D.Sc., D.Eng., M.I.E.E., A.M. Inst. C.E.' Head of the Electrical Engineering Department, University of Sheffield. 262 pages, 25 x 18 cm., cloth. New York, D. Van Nostrand Company, Inc., 1927. Price, $8.

Research workers must ever rely upon periodical literature for information on the subject of their investigation for it is only from such sources that recent enough data; and in its original form may be found, but there are many more users of scientific literature, whose needs are less critical, to whom such literature is not available. For them, a well-arranged text-book containing recent data often is a more efficient source of information, and either new books or revised editions of old ones must appear at reasonable intervals. The appearance of the two works before us is in harmony with these circumstances. The first mentioned deals specifically with the properties and testing of magnetic materials; the second is more of a general treatise in its scope, and both contain recent information.

Mr. Spooner's work is devoted chiefly to a consideration of the magnetic properties of commercial ferro-magnetic materials and to a description and discussion of the various useful methods of test suitable for commercial inspection and for research. Only a brief outline of the relations of the quantities of the magnetic circuit is given, a knowledge of these fundamentals being assumed. In the first of the three divisions of the work which occupies one-half the volume a review is made of the quantities represented by magnetization and permeability curves; then, proceeding to normal hysteresis and eddy-current losses, range of permeability and core-loss values for various irons and their alloys are analyzed at length. A short description of some non-magnetic ferrous alloys is included. The chapter on permanent magnet steels, their composition, treatment and properties, adds materially to the gradually accumulating collection of rational information on the "trade secrets" of this art. Then follow chapters on hysteresis under special conditions and effects of frequency on apparent permeability and iron losses.

The effects of direction of grain and mechanical stress on magnetic properties, under which are included the effects of rolling and punching and shearing of sheet material, are given a chapter of considerable length. The phenomenon of magnetostriction is accorded a brief account only as having little bearing in its present

development on commercial applications. Other "effects," it may be noted, important as they are in their relation to atomic theory, are also ignored for a like reason. The important factor of annealing electrical sheet and the heat-treating of permanent-magnet steels is given space in keeping with its importance. Another chapter deals with reversible temperature effects as distinguished from the permanent temperature effects of the previous chapter. Chapters on alternating magnetizing current and on the mechanical properties and thermal conductivity of electrical sheet complete the first part of the work.

The second part constitutes a treatise on commercial magnetic testing and is distinctive in laying stress upon commercially applicable methods and apparatus. This part of the subject is sub-divided into the two main divisions of direct-current testing and alternating-current testing. Under the former division are considered numerous methods and lay-out of apparatus for the measurement of induction and magnetizing force and, under the latter, those applicable to the determination of losses under alternating-current flux. A chapter on core-losses in transformers and in rotating machines, and on magnetic analysis, constitutes the third part. The latter is on the promising system of testing the physical condition and properties of materials from their magnetic qualities. The work is thoroughly documented by references to original sources at the end of each chapter which relate to the topics there discussed. The volume contains an immense amount of thoroughly analyzed and carefully appraised applicable data in irreproachable typographical setting.

Professor Wall's work deals with principles as well as with application. In a first part of this work, the principles of applied magnetism are considered; in the second part, magnetic testing. Under Part I are developed first the usual formulas connecting the quantities which express the phenomena of magnetic induction and an account of the molecular theory of magnetism. Proceeding to application, there is fully discussed in the second chapter the theory of permanent magnets. In addition to the analytical deductions of this chapter many matters of practical interest are included. The third chapter covers a collection of metallurgical facts of unusual interest and their relationship to the magnetic properties of iron and steel and the fourth some characteristics of magnetic substances. In the latter are some very interesting data on permanent magnet steels, on the now well-known and much appreciated "permalloy" and the recent Ferranti non-magnetic cast iron. The fifth chapter contains an analytical and experimental account of reluctivity and the Fröhlich-Kennelly relationship. Magnetostriction which has received much attention from recent investigators is given the sixth chapter. The discovery of the electron and the development of the electron theory of matter which has placed the 100-year-old Ampère theory of magnetism on a firm foundation of experimental fact is considered in the seventh chapter. With view to testing the possible change of the magnetic properties due to a change of electronic orbits under an intense magnetic field, a full account is given in chapter eight of the author's method and apparatus for producing a field of the order of 500,000 gausses by means of condenser discharge.

Under part two, various methods of magnetic testing are considered. In this are included the ballistic galvanometer, the fluxmeter, determination of magnetization curve and hysteresis loop; bar-and-yoke method; magnetization curve and hysteresis loop by magnetometer method; total losses in iron laminations; measure-

ment by means of the magnetic square; separation of the losses; hysteresis loop for transformer cores by Scott's method. In the last chapter are discussed the testing of permanent magnets; testing of feebly magnetic substances and testing for mechanical and other defects in steel by magnetic methods, a mode of testing which the author states is giving promise of great practical value.

The work is set up in somewhat larger type than is usual in works of this sort and the text is correspondingly comfortable to read; that feature necessarily increases the size of the volume. The subject is presented with great clarity and in its modern aspects.

LUCIEN E. PICOLET.

PYROXYLIN ENAMELS AND LACQUERS, THEIR RAW MATERIALS, MANUFACTURE AND APPLICATION. By Samuel P. Wilson, M.A., Ph.D. Second edition, enlarged. xv–253 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1927. Price, $3.50.

The soluble cottons obtained by nitrating the natural form have been known for many years. For a long while their principal use was for explosives. In this use they produced very profound modifications in the art of war but did not get the application for engineering purposes that the corresponding derivatives from glycerol and the phenolic bodies have obtained. From an early period, however, in the history of pyroxylins, their solubility in some familiar liquids led to their use as coatings of various kinds. Many years ago the so-called wet process of photography was invented, based on the use of a solution of nitrated cotton in a mixture of alcohol and ether which, allowed to evaporate, gave a very satisfactory coating on the glass plate as a carrier for the sensitive emulsion. It is necessary also to note the very important product celluloid which has found so many applications, especially as a substitute for bone and ivory. The applications of these cotton products through the productions of varnishes and enamels have greatly extended their usefulness and manufacture. The present work is a summary of the technology of this subject and begins by describing the manufacture of the nitrated material and a description of its properties; then a large amount of space is devoted to the solvents which are quite numerous and are grouped as alcohols, esters and ketones; also a number of liquids which are not solvents are included in these descriptions. It is to be regretted that the coal tar products of the closed chain type are referred to as benzol, toluol and xylol instead of with their proper termination "ene," but it seems hard to drive out of the practical worker these erroneous methods of expression. The plasticisers and the many accessory substances which are added to the solutions in order to adapt them to a variety of uses are described in detail. Part 2 is devoted to bronzing liquids and to those applications which are called by the curious name of "dopes." The work concludes with a description of a variety of analytic methods, including some suggestions for avoiding the hazards attending the use of such materials. The work contains therefore a very large amount of information of a practical character on a line of industry which is of comparatively recent development and of widespread application.

HENRY LEFFMANN.

PROTECTIVE METALLIC COATINGS. By Henry S. Rawdon, Senior Scientist (Metallurgy) United States Bureau of Standards. American Chemical Society Monograph Series. 277 pages, 23 x 15 cm., cloth. New York, The Chemical Catalog Company, Inc., 1928. Price, $5.50.

Protecting a metal surface against corrosion is most obviously attained by the application of a coating which excludes atmospheric or other corrosive influences. To be fully effective, such a coating must be intact at all points and the necessity for the repainting of exposed metallic structures at periodic intervals is a familiar illustration of that requirement. With certain metallic coatings, like the old and tried "galvanizing," an additional protection is afforded, at points where the coating is imperfect, by the electrolytic relation between the coating-metal and the surface which it protects. The very term "galvanized" early applied to zinc-coated iron suggests an equally early appreciation of the virtue of this electrolytic feature. Another action of value in this and other dipping processes is the firm adhesion of the coating which results from the alloying of two metals at the surfaces of contact. Accordingly a consideration of the electrolytic behavior of metals in contact and the formation of alloys under the conditions of plating operations are important features in the study of protective metallic coating processes. These matters are kept much in the foreground in the presentation of the subject.

The work is arranged in three divisions. First, a survey of coating methods, then a discussion of commercial metallic coatings, and lastly methods of testing metallic coatings. Before proceeding with specific topics, an introductory chapter contains an account of the principles which govern metallic coating processes and an illuminating discussion of the electrolytic corrosion of metals in contact. Under "coating methods" the principles, nature and practical application of coating methods depending upon the alloying of coating and base, electroplating and metal spraying and sprayed metal coatings are examined at considerable length. The last method is given the largest share of attention in this preliminary discussion of plating processes but is not further considered among the analytical and practical details which follow. As compared with the older processes, metal-spraying is a recent arrival in the field of metal coating but it has already been applied to such work as the hulls of ships, bridges, railway-car under-frames and other large work. In regard to its future, the author says: "On the whole, it seems that the metal-spraying process has not yet settled down to its proper place. This is only a matter of time, however, since the value, importance and practicability for many purposes of the metal-spray method has been demonstrated again and again."

Zinc-coating by hot-dipping or galvanizing and tin-coating receive a large share of attention in keeping with their important position in the metal industries. In these chapters, many details of practical value and analytical interest are included. There is also a study of microstructure of iron-zinc alloys with numerous photo-micrographs of cross-sections and surfaces of coatings. Electroplating, as well as dipping and cementation processes for both zinc and tin receive adequate attention. There are chapters on coatings of copper, nickel, chromium and cobalt, coatings of lead, cadmium and aluminum, and gold and silver coatings. All of these receive the same physico-chemical examination as is accorded to the plate-industries. Miscellaneous finishes and methods of testing metallic coatings

complete the work. An unusually extensive classified bibliography is appended.

The work is unique in its full presentation of the subject and its logical treatment.

LUCIEN E. PICOLET.

PUBLICATIONS RECEIVED.

Wireless Principles and Practice, by L. S. Palmer, M.Sc., Ph.D. 504 pages, illustrations, 8vo. London and New York, Longmans, Green and Company, 1928, price $7.

Fundamentals of Dairy Science, by Associates of Lore A. Rogers in the Research Laboratories of the Bureau of Dairy Industry, United States Department of Agriculture. 543 pages, illustrations, portrait, 8vo. New York, The Chemical Catalog Company, Inc., 1928, price $5.50.

An Introductory Textbook of Electrical Engineering, by John Robert Benton. 347 pages, illustrations, 8vo. Boston, Ginn and Company, 1928, price $3.60.

Appareils et Méthodes de Mesures mécaniques, par le Lt. Colonel Jules Raibaud. 215 pages, illustrations, 16mo. Paris, Librairie Armand Colin, 1928, price, in paper, 9 francs.

Éléments de Thermodynamique, par Charles Fabry, Membre de l'Institut. 216 pages, illustrations, 16mo. Paris, Librairie Armand Colin, 1928, price, in paper, 9 francs.

El Observatorio del Ebro. Idea general sobre el mismo por el Subdirector P. Ignacio Puig, S.J. 188 pages, illustrations, 8vo. Tortosa, Imprenta Moderna, 1928, price 5 pesetas.

Notre Misère Scientifique, Ses Causes, Ses Remèdes. L'appel du Roi par Q. M. Quaeris et des collaborateurs. 55 pages, 8vo. Bruxelles, Fr. Saey, 1928, price 10 francs.

National Advisory Committee for Aëronautics. Technical Notes, No. 273, The effect of performance of a cutaway center section by Thomas Carroll. 7 pages, illustrations, quarto. No. 274, The effect of the Sperry messenger fusilage on the air flow at the propeller plane by Fred. E. Weick. 5 pages, illustrations, quarto. No. 275, Determination of propeller deflection by means of static load tests on models by Fred. E. Weick. 7 pages, illustrations, quarto. No. 277, Pressure distribution on wing ribs of the VE-7 and TS airplanes in flight by R. V. Rhode. 6 pages, illustrations, quarto. No. 278, An automatic speed control for wind tunnels by A. F. Zahm. 15 pages, illustrations, quarto. Washington, Committee, 1928.

CURRENT TOPICS.

American Electrochemical Society Meeting. The Annual Meeting will be held at Bridgeport, Conn., on April 26, 27 and 28. The opening session will be devoted to a discussion of new batteries. A public lecture will be given on Thursday evening by Professor Bergen Davis of Columbia University on the use of the X-ray in the study of metals and compounds. The second session will be given over to a discussion of electric heating, melting and electric furnace linings. The final session will be held on Saturday morning, at which papers will be presented on electroplating of nickel, gold, silver, chromium and thallium.

Twentieth Anniversary of the Federal Food and Drugs Act. On October 20, 1926, a joint conference of the Association of Official Agricultural Chemists, the Association of Dairy, Food and Drug Officials of the United States, and the Association of Feed Control Officials of the United States was held at Washington, D. C., to celebrate the twentieth anniversary of the passage of the Federal Food and Drugs Act, and its approval by President Roosevelt on June 30, 1906. The Proceedings of this conference have been published in a monograph of 69 pages. Among the papers are: "The Rôle of Chemistry in Food and Drug Administration" by W. W. Randall, "The Part the States Have Played in the Pure Food Movement" by Thomas Holt, "Twenty Years of Feed Control" by F. D. Fuller, "The Relation of Research to Control" by C. A. Browne, "Food Industries and Regulation" by Charles Wesley Dunn, "Lux et Veritas" by Harvey W. Wiley. J. S. H.

Chemistry, Biology, and Medicine. In his Willard Gibbs lecture, JOHN J. ABEL of Johns Hopkins University (*Science*, 1927, *66*, 307–319, 337–346) discusses the relationship of chemistry to biology and medicine since the days of Paracelsus, who fused chemistry and medicine during the first half of the sixteenth century. Respiration was studied by Robert Boyle, John Mayow, and Lavoisier. The later work of Magnus, Pflueger, Ludwig and Lothar Meyer developed the modern theory of both internal and external respiration. In 1828 Wöhler synthesized urea. The researches of physiological chemists from the days of Liebig, Wöhler and Dumas to those of Emil Fischer and Willstätter have explained many physiological processes and the chemistry of many compounds of biological importance such as the sugars, the proteins, the

purines, the tannins, the enzymes, and the respiratory pigment of the blood and the assimilatory pigments of plants. Physical chemistry has stressed the importance of surface in reactions; thus the interchange of oxygen in the inspired air for carbon dioxide in the venous blood occurs in the alveoli of the lungs. The lungs contain about 725,000,000 alveoli which have a total internal area of approximately 100 square meters. This large area permits the gas exchange to occur in the period of less than 4 seconds which is required for each respiration. The hormones are chemical messengers which are secreted by the endocrine glands, pass into the blood stream, and cause some distant nerve cell or other organ to perform some definite function. While numerous hormones are known, but few have been isolated, and only two—epinephrine and thyroxine—have been synthesized. Epinephrine is the hormone secreted by the medulla of the suprarenal glands; it has a specific action on the sympathetic nervous system, for instance, it gives rise to constriction of the blood vessels, relaxation of constricted bronchioles of the lungs, increased rapidity of heart action, and other symptoms. Thyroxine governs the basal metabolic rate of the body; it is secreted by the thyroid gland. The structural formula of each of these two hormones has been ascertained. Insulin is the hormone secreted by the histological units of the pancreas known as the islands of Langerhans. While its structural formula is, as yet, unknown, insulin has been isolated in the crystalline form; thus, when 2001 grams of commercial dry insulin powder, containing 13 insulin units per milligram, were used, they yielded 0.5284 gram of crystalline insulin, each milligram of which had a value of 40 insulin units. The crystals yield certain protein reactions, but apparently do not contain tryptophane, free cystine, or cysteine; they apparently are dimorphous; their solutions are lævorotatory. Insulin has the empirical formula $C_{45}H_{69}O_{14}N_{11}S$ when dried in an atmosphere of nitrogen at a temperature of 105° to 120° C.; the air-dried material contains 3 molecules of water of crystallization. Approximately 37.5 per cent. of the total sulphur is in a labile or "carbonate" form. A deficient secretion of insulin by the islands of Langerhans gives rise to the disease known as diabetes mellitus.

J. S. H.

Atomic Weight Table. The American Chemical Society table of Atomic Weights for 1928 has been prepared by GREGORY PAUL BAXTER of Harvard University (*Jour. Am. Chem. Soc.*, 1928, *50*, 603–617). Five changes have been made from the table for 1927; the new values for 1928 are: Helium 4.002, Argon 39.94, Dysprosium 162.46, Neon 20.183, and Yttrium 88.92. J. S. H.

New Regulations. The Food, Drug, and Insecticide Administration of the U. S. Department of Agriculture issued Regulations for the Enforcement of the Federal Food and Drugs Act in October (Service and Regulatory Announcements, Food and Drug No. 1, 19 pages). In December, the same Administration issued Definitions and Standards for Food Products (Service and Regulatory Announcements, Food and Drug No. 2, 20 pages), including meats and meat products; milk and milk products; grain products; fruit and vegetables; sugars and related substances; condiments; tea, coffee and cacao products; beverages; wines; vinegar; salt; and baking powder. In February, a supplement was issued containing amendments to these definitions and standards with respect to sage and tea (Service and Regulatory Announcements, Food and Drug No. 2, Supplement No. 1, 1 page).

In December, this Administration also issued Regulations for the Enforcement of the Caustic Poison Act (Service and Regulatory Announcements, Caustic Poison No. 1, 12 pages).

The regulations for the enforcement of each act contain the text of the act in question, as well as the regulations for its enforcement.

J. S. H.

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